University of Alberta

Effects of Chronic Industrial Noise Disturbance on Boreal Forest Songbirds

by

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Abstract

As energy development expands into Alberta's boreal forest, sources of chronic industrial noise also increase. I found that many passerine species are present in lower densities in areas impacted by chronic industrial noise; over one-third of species analysed had lower abundances in these areas. Passerines as a whole had a 37% reduction in density near compressor stations. Male Ovenbirds (*Seirus aurocapilla*) were 15% less likely to successfully pair with a female in noise-affected areas. There was an 18% increase in the number of first-year breeders in noisy areas, implying that competition with older birds may be forcing younger birds out of optimal, quieter habitat. Finally, if birds learn to alter their song's frequency in areas with substantial background noise these effects may be minimised; Swainson's Thrush (*Catharus ustulatus*) appears to have this ability although the Ovenbird and Red-eyed Vireo (*Vireo olivaceus*) do not.

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Dedication

This thesis is dedicated to my grandfather, Najeeb Rossy, who has always wanted me to write a book about ecology – this is my first attempt.

Table of Contents

Chapter 1. Introduction **1**
1.1 Bird Communication 1
1.2 Previous Chronic Noise Studies 2
1.3 Industrial Noise in Alberta's Boreal Forest 3
1.4 Thesis Overview 4
1.5 Literature Cited 8
Chapter 2. Is bird occurrence or abundance impacted by chronic industrial noise? **10**
2.1 Introduction 10
2.1.1 Noise effects on bird occurrence and abundance 10
2.1.2 Detectability issues 11
2.1.2.1 Occupancy estimation 11
2.1.2.2 Removal modeling 12
2.2 Study Area 13
2.2.1 Location 13
2.2.2 Site selection 13
2.3 Methods 14
2.3.1 Point count methods 14
2.3.2 Covariate measurements 14
2.3.3 Detectability adjustments and statistical analysis 15
2.3.3.1 Field test of detectability 15
2.3.3.2 Relative abundance estimation 16
2.3.3.3 Occupancy estimation 16
2.3.3.4 Removal modeling 17
2.4 Results 17
2.4.1 Field test of detectability 17
2.4.2 Relative abundance estimation 17
2.4.3 Occupancy estimation 18
2.4.4 Removal modeling 18
2.5 Discussion 18
2.6 Conclusions 21
2.7 Literature Cited 30

Chapter 3. Effects of chronic industrial noise on Ovenbird pairing success and age structure **32**
3.1 Introduction 32
3.1.1 Pairing success 32
3.1.2 Ovenbird age 33
3.2 Study Area 34
3.2.1 Location 34
3.2.2 Site selection 35
3.3 Methods 35
3.3.1 Ovenbird capture 35
3.3.2 Pairing observations 36
3.3.3 Ovenbird age 37
3.3.4 Territory vegetation measurements 37
3.3.5 Statistical analysis 38
3.4 Results 39
3.4.1 Pairing success 39
3.4.2 Ovenbird age 40
3.4.3 Body morphology and condition 40
3.4.4 Individual quality vs. habitat quality 41
3.5 Discussion 41
3.5.1 Pairing success 41
3.5.2 Ovenbird age 44
3.6 Conclusions 45
3.7 Literature Cited 51
Chapter 4. Song alteration as a consequence of chronic background noise **54**
4.1 Introduction 54
4.2 Study Area 55
4.2.1 Location 55
4.2.2 Site selection 56
4.3 Methods 56
4.3.1 Song recording 56
4.3.2 Song analysis 56
4.4 Results 57
4.5 Discussion 58

4.6 Conclusions 60
4.7 Literature Cited 65
Chapter 5. Synthesis and Management Implications 67
5.1 Synopsis of Findings 67
5.2 Limitations and Future Research 67
5.3 Current Noise Guidelines and Recommendations 69
5.4 Literature Cited 71

Table of Tables

Table 2.1. Mean number of birds detected (and standard error) of various bird species (full species names can be found in Table 2.6). Data used in the analysis were from a series of point counts conducted in northeastern Alberta in areas of high and low chronic background noise, 2003-2004. "Treatment" refers to sites located near chronically-noisy energy industry facilities, versus control sites near similar, but noiseless, facilities. In the species column, "All Pass" refers to all passerines combined. 22

Table 2.2. Estimated coefficients (and resulting constant) for four variables used in a generalized estimating equation analysis of densities of various bird species (full species names can be found in Table 2.6). Data used in the analysis were from a series of point counts conducted in northeastern Alberta in areas of high and low chronic background noise, 2003-2004. "Treatment" refers to sites located near chronically-noisy energy industry facilities, versus control sites near similar, but noiseless, facilities; a negative coefficient implies that particular species had lower densities in noisy areas. Vegetation is a composite variable derived from factor analysis which is positively associated with shrub cover. Shaded cells represent significant variables ($P<0.05$). In the species column, "All Pass" refers to all passerines combined. 23

Table 2.3. Models for a series of occupancy estimation models derived by Program MARK. Data used in the analysis were from a series of point counts conducted in northeastern Alberta in areas of high and low chronic background noise, 2003-2004. For each passerine species, eight models were evaluated and Akaike weights (w_i) were summed for all models which included a "noise treatment" parameter that affected occupancy or detection probability. This "weight of evidence" procedure allowed me to evaluate the overall importance of the treatment effect across models (Burnham and Anderson 2002). Shaded cells had $\sum w_i > 0.6$ and were considered to be significant. Also shown are best models as determined by AIC_c and their associated Akaike weights. ψ represents the occupancy rate of a site, while p represents the detection probability; g refers to a parameter varying across treatment groups, while "." refers to that parameter being constant across treatments. *Shrub* represents a principal component axis measure of vegetation which is positively correlated with shrub cover. Full species names can be found in Table 2.6. 24

Table 2.4. Estimated detection probabilities and densities from removal modeling following Farnsworth *et al.* (2002). Data used in the analysis were from a series of point counts conducted in northeastern Alberta in areas of high and low chronic background noise, 2003-2004. "Compressor" sites were located near chronically-noisy energy industry facilities, while "control" sites were located near similar, but noiseless, facilities. In the species column, "All Pass" refers to all passerines combined. Full species names can be found in Table 2.6. 25

Table 2.5. Summary of results from four analysis methods conducted to assess passerine densities in the presence of chronic industrial background noise. Data were collected using point counts in northeastern Alberta, 2003-2004. "Compressor" sites were located near chronically-noisy energy industry facilities, while "control" sites were located near similar, but noiseless, facilities. In the table, "Ctrl" represents significantly higher densities (or occupancy rate) found at control sites ($P<0.05$); "Comp" represents the opposite. "-" means that the analysis could not be conducted for that species for statistical reasons. In the species column, "All Pass" refers to all passerines combined. "Prop.

reduced" is the proportion of species analysed which showed significant density or occupancy reductions at compressor sites. Full species names can be found in Table 2.6. 26

Table 2.6. Common and scientific names for bird species used in analysis for a study on the effects of chronic industrial noise on birds in northern Alberta, Canada. Approximate song frequency ranges are from Borror and Gunn (1985) and Birds of North America Online (Cornell University, Ithaca, NY)..... 27

Table 3.1. Summary of male Ovenbirds captured and banded per treatment per year, and the number of birds on which pairing observations were made. "Compressor" sites had a noise-generating compressor station at the centre of a forest clearing, while "control" sites had a noiseless wellhead at the centre. The study was conducted in northern Alberta in 2004 and 2005..... 47

Table 3.2. Contingency table illustrating Ovenbird pairing success and age distribution between treatments. SY birds are first-year breeders, while ASY birds are in at least their second breeding season. "Compressor" sites had a noise-generating compressor station at the centre of a forest clearing, while "control" sites had a noiseless wellhead at the centre. The study was conducted in northern Alberta in 2004 and 2005. 47

Table of Figures

Figure 1.1. A typical natural gas compressor station in boreal Alberta. The aluminium shed houses three large motor and fan units. Photo: Lucas Habib. 6

Figure 1.2. An example of a large, low-frequency noise-generating fan unit on the exterior of a compressor station in boreal Alberta. For scale, there is a typical oil barrel in the photograph. Photo: Martin Lankau. 6

Figure 1.3. A decommissioned wellpad near Wabasca, Alberta. Two seismic lines and one pipeline are running through it. Photo: Boyan Tracz. 7

Figure 2.1. Map of the two study areas located in northern Alberta, Canada, for a study on the effects of chronic industrial noise on birds. Point counts were conducted in the northeastern study area (NEA) in 2003 and 2004. 28

Figure 2.2. Map of the northeastern study area (NEA) located in northern Alberta, Canada. The study on the effects of chronic industrial noise on bird abundance and occupancy was conducted in the area in 2003 and 2004, while the Ovenbird pairing success study was conducted there in 2004. The Alberta-Pacific Forest Industries, Inc. Forest Management Agreement is shown in the lighter shade. 29

Figure 3.1. Map of the northwestern study area (NWA) located in northern Alberta, Canada. The study on the effects of chronic industrial noise on Ovenbirds was conducted in the NEA in 2004 (Figure 2.2) and in the NWA in 2005. 48

Figure 3.2. Study design for Ovenbird capture in northern Alberta in 2004 and 2005. One Ovenbird was captured on each side of an energy industry-created clearing (territories indicated by grey polygons). Compressor sites had a noise-generating compressor station (house icon) at the centre of the clearing, while control sites had a noiseless wellhead (diamond icon) at the centre. 49

Figure 3.3. Examples of feather tips from a second-year (SY) Ovenbird and an after-second-year (ASY) Ovenbird. Feathers of SY birds have a sharper tip angle as is highlighted. 49

Figure 3.4. Ovenbird territory vegetation assessment protocol. All trees intersecting the 1-m wide transects had their DBH measured, and all DWM intersecting the transects were tallied. In the 0.25-m^2 plots, shrub density, leaf litter depth, and grass, moss, and forb cover were measured. The study was conducted in northern Alberta in 2004 and 2005. 50

Figure 4.1. Birds may adjust their song in the presence of background noise to reduce interference with the noise. There are two ways this may occur: by shifting the song's frequency to a region on the spectrum with less overlap, or by increasing the song's amplitude. When the latter occurs as a short-term reflex response, it is called the Lombard effect and has been demonstrated by many species (Reprinted with permission from Katti and Warren 2004). 61

Figure 4.2. Minimum frequency of Ovenbird song increases slightly with increasing maximum frequency of chronic industrial background noise (β=0.12, R^2=0.04, P=0.18). Recordings of edge-dwelling male birds were made in northeastern Alberta during the 2004 breeding season. 62

Figure 4.3. Minimum frequency of Swainson's Thrush song increases with increasing maximum frequency of chronic industrial background noise (β=.25, R^2=0.21, P=0.04). Recordings of edge-dwelling male birds were made in northeastern Alberta during the 2005 breeding season. 63

Figure 4.4. Minimum frequency of Red-eyed Vireo song decreases slightly with increasing maximum frequency of chronic industrial background noise (β=-0.08, R^2=0.04, P=0.23). Recordings of edge-dwelling male birds were made in northeastern Alberta during the 2005 breeding season..... 64

CHAPTER 1. INTRODUCTION

1.1 Bird Communication

Birds communicate primarily through vocalizations. Males of territorial species use song to advertise their breeding status to females (Lein 1980), provide an indicator of their quality as potential mates (Gil and Gahr 2002, Nowicki and Searcy 2005), demarcate and passively defend territory boundaries (Lein 1980, Lemon *et al.* 1981), identify neighbouring males (Brenowitz 1982), and assess the physiological state of conspecifics (Naguib 1996). Habitat conditions influence the transmission efficiency of song (*i.e.* bird song degrades more quickly in a closed than open environment) and many bird species use habitat-specific rates of song degradation to evaluate the distance to and intention of a vocalizing conspecific (Naguib 1996, Balsby *et al.* 2003, Slabbekoorn 2004). As a result, each species' song has evolved to transmit clearly and effectively over some certain distance in their preferred habitat; in territorial forest songbirds, this distance is usually about the average radius of one territory (Lemon *et al.* 1981).

Birds live in naturally-noisy environments (Brenowitz 1982, Ryan and Brenowitz 1985, Slabbekoorn 2004). At the extreme low end of the frequency scale is wind-caused rustling of foliage and rushing water, at the high end is insect noise (Brenowitz 1982). Vocalizations of other bird species, amphibians, and mammals create noise over a wide range of frequencies which may also interfere with a specific signal (Slabbekoorn 2004). This "masking" effect is greatly dependent on the properties of both the signal and the interfering noise. The structure of the environment can also influence transmission of signals and how they interact. Vegetation structure in forested environments greatly increases the attenuation of sound, but also increases reverberations, which can be beneficial or detrimental to a signal depending on its properties and purpose (Huisman and Attenborough 1991, Slabbekoorn *et al.* 2002).

Despite the multitude of factors affecting birdsong transmission, birds have evolved song characteristics that are best suited to effectively communicating in their preferred habitat (Slabbekoorn 2004). For example, birds living in dense forests typically have songs that are characterized by relatively low frequencies, which

enhances transmission in that habitat type (Slabbekoorn *et al.* 2002). Given the importance of song to birds, any changes in the background acoustic environment could have implications for songbird behaviour and population dynamics. This raises concerns that increasing levels of anthropogenic noise may affect birds negatively. Since much mechanical noise is low-frequency, it can transmit considerable distances (Bolstad Engineering Associates 1978, Brenowitz 1982), creating a large zone of interference with bird song communication. In environments where anthropogenic noise is present, male birds may be unable to transmit their song as clearly or over as great a distance as under quiet conditions. Reduced song transmission effectiveness may decrease the number of females that hear an individual male's song and/or result in females receiving false information about a male's quality (Slabbekoorn 2004). Difficulties may also occur in the ability of birds to estimate distance to conspecifics, which could result in more frequent aggressive interactions between neighbouring males; if a bird cannot hear his neighbour's song at the boundary of his territory, he may be more likely to violate a territory boundary or attempt to claim the neighbour's territory as his own. Ultimately, an inability to communicate effectively with conspecifics could reduce the quality of habitat for birds and result in avoidance of noisy areas.

1.2 Previous Chronic Noise Studies

The limited work done in the area of chronic noise and birds has mostly examined the effects of traffic noise near highways. Some species of birds have been found to exhibit reduced breeding densities in areas around roads, with noise assumed to play a larger role in that reduction than visibility of cars or traffic mortality (Reijnen *et al.* 1995, Kuitunen *et al.* 1998). Some species also have reduced breeding success (*i.e.* a lower probability of mating and successfully rearing young) near roads (Reijnen and Foppen 1994, Burke and Nol 2000, Kuitunen *et al.* 2003). However, it has never been conclusively demonstrated that the noise generated by roads is the factor that results in reduced breeding activity in birds; the myriad other factors that roads alter (*e.g.* edge effects, traffic-caused mortality) have not been effectively controlled for. Simply comparing bird responses at varying distances from roads

confounds noise effects with edge effects created by roads. A better system is needed to fully understand the effects of noise on bird behaviour and population dynamics.

1.3 Industrial Noise in Alberta's Boreal Forest

Boreal Alberta is one of North America's most intense oil and natural gas production areas. While energy sector development began in the mid-20th century in this region, the last two decades have seen exponential growth of the industry. Associated with increasing energy and forestry industry activity are roads, other linear features, and amplified human recreational presence such as off-road vehicles. The noise profile of boreal landscapes is changing due to this greatly increasing amount of anthropogenic noise. While much of this noise is acute in nature (*e.g.* truck traffic, logging, construction of a gas plant), many energy facilities produce chronic noise once operational.

Throughout Alberta, a network of pipeline systems connects natural gas gathering sites and wells to processing facilities, and ultimately, transport terminals. Along these pipeline systems lie compressor stations, which function to boost pressure in the pipelines and help maintain the flow of natural gas and oil from wells (Figure 1.1). A typical compressor station consists of one to three motors cooled by an equal number of large fan units (Figure 1.2); the machinery is housed in an aluminium shed on a 1- to 4-ha clearing in the forest. Motors and fans on compressors run continuously aside from infrequent maintenance and typically produce noise levels of 75 to 90 dB(A) near the source (Bolstad Engineering Associates 1978, ATCO Noise Management 2003). Very large compressor stations can reach levels of 105 dB(A) at the source (Mac Donald *et al.* 1996). This noise range is approximately equivalent to constant semi-trailer traffic on a four-lane expressway (ATCO Noise Management 2003).

Noise decay from compressor stations occurs logarithmically; under "free field" conditions, noise is reduced by 6 dB(A) for every doubling of distance from the source (ATCO Noise Management 2003). This degradation rate is accelerated in forested systems depending on the structure of the forest and understory (Huisman & Attenborough 1991). However, despite this reduction in amplitude, low-frequency

mechanical noise can be transmitted very far from the source even in closed forest environments (Bolstad Engineering Associates 1978, Brenowitz 1982). On a clear, quiet day, compressor stations can be easily heard well over 1 km from the source (pers. obs.).

Like roads, compressor stations in forest environments are associated with a significant amount of edge habitat. Simply comparing bird responses at various distances from compressor stations confounds noise effects with edge effects. However, in boreal Alberta the pipeline and road systems are also associated with wellpads. Similar to compressor stations, wellpads are clearings of 1 to 2 ha of forest habitat that are linked via narrow linear features such as pipelines and single-lane road access (Figure 1.3). Unlike compressor stations, however, wellpads produce no chronic noise and thus provide an effective experimental control for separating the effects of edge relative to noise.

1.4 Thesis Overview

In this thesis, I provide an analysis of possible effects of chronic industrial noise on bird behaviour and populations in the boreal forest of Alberta, using compressor stations as the source of that noise and wellpads as controls. I propose that birds may react to compressor station noise in five ways: 1) they may avoid compressors and choose to settle in a different place completely (*i.e.* complete avoidance); 2) males may settle by a compressor but be unable to attract a female due to distortion of their songs; 3) older males may secure better quality habitat, pushing younger birds into noisier areas; 4) males might adapt and change their song to make it more detectable in the face of noise, resulting in no change in abundance or pairing success; or 5) noise has no discernable effect on birds. The specific questions I will be asking based on these ideas are: 1) does chronic noise result in species with low-frequency songs avoiding the area around compressor stations; 2) is total bird density reduced around compressor stations; 3) does chronic noise result in reduced mating success for Ovenbirds (*Seiurus aurocapilla*); 4) are second-year Ovenbirds (first-time breeders) more common near noisy areas than more experienced breeders; and 5) do breeding birds adapt their song to transmit more efficiently in noisy areas?

In Chapter 2, I examine how occurrence and abundance of birds in noisy and quiet areas differs. I use statistical methods to account for the reduction in the ability of human observers to detect birds in noisy areas when estimating patterns of occurrence and abundance. Density is not always a good indicator of the quality of a habitat for birds (Bock and Jones 2004). In Chapter 3, I investigate whether there are differences in pairing success and age structure between populations of Ovenbirds in noisy and quiet areas. In Chapter 4, I explore whether a limited subset of bird species are able to adapt their songs to enhance transmission in areas of background noise. In Chapter 5, I summarise my findings and discuss the implications for the energy industry in terms of best practices related to noise management. Results of this study are intended to inform future noise assessments and noise control directives, while also providing one of the first tests of noise impacts independent of edge effects and other confounding factors.

Figure 1.1. A typical natural gas compressor station in boreal Alberta. The aluminium shed houses three large motor and fan units. Photo: Lucas Habib.

Figure 1.2. An example of a large, low-frequency noise-generating fan unit on the exterior of a compressor station in boreal Alberta. For scale, there is a typical oil barrel in the photograph. Photo: Martin Lankau.

Figure 1.3. A decommissioned wellpad near Wabasca, Alberta. Two seismic lines and one pipeline are running through it. Photo: Boyan Tracz.

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CHAPTER 2. IS BIRD OCCURRENCE OR ABUNDANCE IMPACTED BY CHRONIC INDUSTRIAL NOISE?

2.1 Introduction

2.1.1 Noise effects on bird occurrence and abundance

Density is frequently used by ecologists as a proxy for habitat quality. It is generally assumed that if a species is found in large numbers in an area, then that environment is likely suitable for survival and reproduction. Forest birds exhibit reduced breeding densities in areas around roads, suggesting that this habitat is of lower quality than forest interior (Reijnen and Foppen 1994, Reijnen *et al.* 1995, Reijnen *et al.* 1996, Reijnen *et al.* 1997, Kuitunen *et al.* 1998, Forman and Deblinger 2000, Brotons and Herrando 2001, Rheindt 2003, Peris and Pescador 2004). In the Netherlands, 26 of 43 woodland passerine species (60%) had reduced densities in areas adjacent to roads when compared to paired plots an average of 400 m away (Reijnen *et al.* 1995). In Finland, 38 of 55 woodland passerine species (69%) exhibited a similar pattern (Kuitunen *et al.* 1998). Roads alter a wide variety of ecological processes for birds. Reduced bird abundance near roads could be due to avoidance of cars via visual cues, higher mortality risk due to traffic-related deaths of birds, increased pollution, altered microclimate, and a myriad of other potential edge effects. However, most research on roads has concluded, albeit with little direct evidence, that traffic noise is the major factor resulting in reductions in bird density (Reijnen and Foppen 1994, Reijnen *et al.* 1995).

Some species of passerines seem more susceptible to road effects than others. Previous work has been unable to isolate the mechanisms underlying this pattern, but Rheindt (2003) demonstrated that birds with higher-pitched songs were found in greater relative abundance near a road compared to other species. This suggests that noise interference with song may cause birds to avoid such areas, ultimately resulting in reduced density. However, the difficulty with such studies is that the type of anthropogenic noise used varies simultaneously with other confounding factors. A system is needed whereby the effects of these confounding factors can be controlled more efficiently. Comparison of compressor stations to wellpads provides the

opportunity to isolate the effects of noise from confounding road effects and provides a more explicit test of the potential impacts of noise on birds.

2.1.2 Detectability issues

A major, yet oft-ignored issue with bird density assessments using auditory cues is that of detectability (Farnsworth *et al.* 2002, Rosenstock *et al.* 2002). Detectability has two components: the probability that a bird which is present at a count station sings during a count, and the probability that an observer hears it given that it sings (Farnsworth *et al.* 2002). Many factors can reduce bird probability of detection, including precipitation, wind, vegetation, observer ability, and bird behaviour. The vast majority of studies assume that the probability of detection is consistent between different habitats, and simply discount the issue of detectability (Ralph *et al.* 1995). However, this assumption is often violated, which can dramatically influence estimates of occurrence or abundance. Reducing the effects of detectability on these estimates can be accomplished by various methods, such as standardizing the conditions under which counts are performed or reducing the size of the sampling radius of the point count. However, inherent in studies of bird response to ambient noise is the possibility of a detectability bias caused by the noise treatment itself. This conflict leads to a critical problem: if more birds are detected at control points is it due to a greater bird density in those areas or to reduced detectability at the noisy points? Recent advances in statistical modelling allow detectability to be estimated, allowing more accurate estimates of occurrence and abundance to be calculated when the assumption of equal detectability due to noise is violated.

2.1.2.1 Occupancy estimation

Point count data are particularly effective at estimating the presence of species. The occupancy estimation model developed by MacKenzie *et al.* (2002) enables evaluation of detectability and adjustment of occupancy estimates and allows for the inclusion of covariates. Wintle *et al.* (2004) found that it worked well with simulated data. A key assumption of this method is that if a species is detected once during repeated visits to a site, it had to be present but was not detected on other visits; however, if a bird is *never* detected at a site it does not imply absence (MacKenzie *et al.* 2002). By repeatedly visiting a site, both occurrence (ψ) and

detectability (p) can be estimated which allows a more precise estimation of occurrence, particularly when detectability varies between experimental treatments.

2.1.2.2 Removal modeling

A similar approach can be used to estimate abundance when detectability varies. By subdividing a count period into time intervals, it is possible to account for both components of detectability by using a removal-experiment approach (*i.e.* if a bird is detected in the first time interval, it is "removed" from the population as it is not counted again during that point count; Farnsworth *et al.* 2002). By comparing the number of birds detected in each time interval, detectability can be estimated.

In this approach, two models are assessed. The first of these models accounts for the first component of detectability by subdividing the birds into two groups – birds which are "easy" to detect and those which are not. It is assumed that "easy" birds will be detected in the first interval, along with a proportion of "difficult" birds. The second model assumes that all birds are in the "difficult" group. The "best model" is passed through Program SURVIV (White 1992) in order to calculate the estimated detectability. Raw counts can then be converted to an estimated bird density with an associated estimated variance. The versatility of this method is that it allows comparisons between observers, time of day, or any other parameter of interest – in this case, the presence or absence of chronic industrial noise.

The objective of this chapter is to determine if the occurrence and/or abundance of birds is lower in noisy environments than in quiet ones after accounting for any differences in detectability between those treatments. Specifically, I will test two methods to deal with detectability and compare them to an analysis of the raw count data. I hypothesize that passerines will be found in lower densities in areas near compressor stations. This effect will likely be more prevalent with species that have lower-frequency songs and are more susceptible to noise interference (Rheindt 2003).

2.2 Study Area

2.2.1 Location

This research was conducted in northeastern Alberta during the spring of 2003 and 2004 (Figure 2.1). The study area was located within the Alberta-Pacific Forest Industries Inc. (ALPAC) Forest Management Agreement area (FMA; Figure 2.2). This region is one of the most highly-developed forestry and energy production regions in Alberta's boreal forest, and as such is permeated with industrial features including roads, wellpads, seismic lines, and pipelines. The ALPAC FMA alone contains over 600 compressor stations in an approximately 7 million-ha area; however, many of these are accessible only by air. The landscape in these areas consists of boreal mixedwood and peatland vegetation (Strong and Leggat 1992). Lowland vegetation is dominated by black spruce (*Picea mariana*) bogs and fens, while upland areas are dominated by trembling aspen (*Populus tremuloides*) and white spruce (*Picea glauca*).

2.2.2 Site selection

Sites were selected in ArcView 3.3 (2004) and ArcGIS 9.0 (2005; ESRI Inc., Redlands, CA) using several criteria (Figure 2.2). Alberta Vegetation Inventory (AVI) data, energy facility data, and road data were provided by ALPAC. All sites were placed entirely in mature aspen forest to reduce vegetation type as a variable determining bird abundance and were ground-truthed to verify that the energy facility was appropriate and vegetation type was accurate. In addition, I discovered many suitable sites while in the field; these sites were evaluated in the GIS to ensure appropriate vegetation cover. All selected sites were truck-accessible. Within a 250-m radius of the site centroid, the predominant overstory type of all sites was trembling aspen. Compressor sites were >3 km apart from other sites to ensure that noise from one site would not reach another. Control sites were occasionally <3 km apart from each other for logistical reasons; however, as no noise was produced at these sites noise contamination was not a concern.

2.3 Methods

2.3.1 Point count methods

Ten-minute 150-m radius point counts were conducted at each site in the NEA in order to estimate bird abundance. Distance of each bird from the observer was estimated within one of six categories: 0 to 25 m, 25 to 50 m, 50 to 75 m, 75 to 100 m, 100 to 150 m, and >150 m. Counts were conducted within 250 m of the centres of selected sites, with each point count location being visited four times over the breeding season. I only considered points that were <250 m in order to enable a direct comparison between "compressor" and "control" sites. Multiple visits allowed me to estimate bird detectability and partially account for weather and observer differences between points (Royle and Nichols 2003). Count locations were a minimum of 200 m apart, located in aspen-dominated forest, and at least 50 m from any anthropogenic edge.

Counts were conducted from 4-30 June in 2003 and from 2-25 June in 2004 between 0424 and 0927 MDT. All counts were done on days with no significant precipitation and little to no wind (≤4 on the Beaufort scale). Bird detections were noted as being within the first 3 min, next 2 min, or last 5 min of the count. Overall, we conducted counts at 54 points (32 points at 13 compressor sites and 22 points at 8 control sites). Non-passerines were excluded from all analyses.

2.3.2 Covariate measurements

Covariates for possible use in analysis were collected at each visit and at each point. Per-visit variables included observer, time, and Julian date. Climatic variables were measured; however, as we conducted four visits to each point these should not have been a concern. Per-point vegetation variables collected were estimated canopy cover, estimated canopy height, shrub height, and shrub cover; shrub cover estimates were based on five categories (0: none present, 1: 1-25% cover, 2: 26-50% cover, 3: 51-75% cover, 4: 76-100% cover). Rather than entering all of the vegetation factors, I chose to use principal components analysis (PCA) in STATA 9.1 (STATA Corp., College Station, TX) to summarize the variation in vegetation structure for each point. All vegetation variables were standardized to zero mean and unit variance

prior to PCA. The first principal component axis summarized 38% of the variation in the vegetation structure. It was heavily loaded for taller shrubs and greater shrub cover – hereafter "shrub level".

2.3.3 Detectability adjustments and statistical analysis

2.3.3.1 Field test of detectability

The first approach I used to assess the issue of detectability was an experimental assessment of the ability of point count observers to hear birds to a distance of 150 m under noisy conditions. I designed a simple point-count simulation protocol which was carried out on a clear, sunny afternoon, when few birds were singing and wind was minimal. It was performed at three point count locations at one compressor station. Background noise at the points varied from 48 to 53 dB(A).

The simulation involved having the two 2004 observers stand back-to-back and perform a simulated point count, consistent with my protocol. Two assistants and myself were equipped with stereos with eight bird songs of different species (Black-and-white Warbler, Lincoln's Sparrow, Magnolia Warbler, Ovenbird, Rose-breasted Grosbeak, Tennessee Warbler, White-throated Sparrow, and Yellow-rumped Warbler). The species were chosen to cover a wide range of song amplitudes and frequencies. Volume was adjusted per song based on previous tests to ensure that amplitude was comparable with songs from real birds of that species, at the given distance. During the simulation, we moved around quietly in the forest playing the songs at those pre-set volumes. Each "caller" had randomized times, bearings, distances from the observers, and songs to play. By knowing this information, I could compare what was played by the "callers" to the data recordings of the observers, thereby allowing me to remove any "natural" bird calls from the analysis. The intended goal of this field test was to determine within various radii whether observers could make accurate determinations of bird species and estimate distance-to-bird. Arguably, if I could demonstrate that my observers made reasonably accurate estimates then it may be sound to use unadjusted bird counts within a particular radius to compare bird abundances under different noise conditions. Results are reported simply as the frequency with which observers correctly identified the position of song playbacks of each species.

2.3.3.2 Relative abundance estimation

To determine if the relative abundance of birds differed between noisy and quiet areas, I used generalized estimating equations (GEE) with a Poisson error structure and an identity link within STATA 9.1. GEEs are a modification of generalized linear models that account for the nested structure in the experimental design, whereby each visit occurs at a point with the point being the primary sampling unit (Hardin and Hilbe 2003). Within the GEE framework, the abundances of birds at each visit to a point are assumed to be correlated to an extent that is estimated by the model. By estimating the exchangeable correlation in density estimates at visits to the same point, estimates of standard errors are robust to any lack of independence.

For this analysis, I used all species that were detected >15 times across all points combined. I chose this cut-off to eliminate rare and uncommon species for whom analyses were likely to be inaccurate. In addition, I examined all passerine species combined. Data from 50-m radius and 150-m radius point counts were used and compared. *A priori* I predicted that noise would result in lower bird densities as it seemed unlikely that changes in the acoustic environment would improve the conditions for birds. Consequently, my tests for noise treatment effects were all one-tailed. Tests for the other nuisance variables (Julian date, time, and shrub level) were two-tailed. All tests were considered significant at P=0.05.

2.3.3.3 Occupancy estimation

Occupancy estimation modeling was conducted using Program MARK as described in §2.1.2.1. The covariate "shrub level" was included as a potential variable of interest; it was assumed that shrub level would only impact occupancy and not detectability. The other nuisance variables were not modelled as they varied across each visit making it impossible to model them directly within MARK. This approach gave a total of eight candidate models. The occupancy estimation model structure described by MacKenzie *et al.* (2002) was used in MARK 4.3 (White and Burnham 1999) and resulting models were assessed within that program using Akiake's Information Criterion for small sample sizes (AIC_c) (Burnham and Anderson 2002). The same species were used for the occupancy estimation analysis

as for the relative abundance analysis; all passerines combined was not used as nearly all counts had at least one passerine detection and would have been very uninformative with respect to presence/absence data.

2.3.3.4 Removal modeling

Removal modeling analysis was conducted as described in §2.1.2.2. I summed multiple visits to one point into a total count for each species at that point across all four visits (Betts *et al.* 2005). The values for each time interval were then entered into Program SURVIV and calculated estimated detection probabilities, densities, and confidence intervals for each species.

2.4 Results

2.4.1 Field test of detectability

All observers who participated in this project felt that regardless of background noise level, they could accurately detect all singing birds within 50 m. This was supported by the results of the field detectability test. For 88.5% of call playbacks at distances up to 150 m, the observers independently identified a bird of the correct species singing at the correct bearing, within the correct 25-m distance band, and at the correct time of a playback. In only one case did an error occur with a playback within 50 m of the observers. This is strong evidence that all bird vocalisations within the 50-m point count detection radius were detected accurately, and most vocalisations at distances of up to 150 m.

2.4.2 Relative abundance estimation

Several species had lower mean abundances at control sites (Table 2.1). Results from the GEE analysis confirmed these discrepancies in response between species. At the 50-m radius, 5 out of 16 species had significantly lower abundances near compressor stations, while at the 150-m radius, 7 of the 16 did (Table 2.2). Overall, species-specific effects were fairly consistent between the two radii (Table 2.2).

2.4.3 Occupancy estimation

With occupancy estimation modeling, none of the top models as evaluated by AIC_c had a very high model weight (all were w_i <0.54; Table 2.3). Therefore, Akaike weights were summed for all models which included a "noise treatment" parameter affecting occupancy or detection probability. This was then compared to the sum of those for which occupancy or detection probability was constant between treatments. This "weight of evidence" procedure allowed evaluation of the overall importance of the noise effect (Burnham and Anderson 2002; Table 2.3). I used a cut-off of $\sum w_i$ >0.6 to determine if the treatment effect was important. As well, the Ovenbird was excluded from the analysis – it was present at nearly every point count and thus occupancy parameters could not be estimated.

The results illustrate that 5 of 15 species had higher probability of occupancy at control sites, while 4 of 15 species had higher probability of detection at control sites. No effects in the opposite direction were observed.

2.4.4 Removal modeling

The removal modeling method of Farnsworth *et al.* (2002) assessed most species as having very high (>0.85), and equal, detection probabilities at compressor and control sites (Table 2.4). In most cases, bird densities were significantly greater at control sites. For all passerines combined, detectability was high (~0.92) and equivalent between treatments. Passerines as a whole had a significantly higher density at control sites (1.4 birds/ha) than at compressor sites (0.9 birds/ha), a difference of nearly one-third. The removal modeling method did not work well for certain species due to low numbers of detections; detection probability could not be properly estimated and hence density estimates were inaccurate for 4 species (Table 2.4).

2.5 Discussion

Roads, compressor stations, wellpads, and pipelines are rapidly increasing in Alberta's boreal forest. The deletion of forest habitat from this anthropogenic activity is undoubtedly affecting the abundance of birds in Alberta. My results suggest that

the physical footprint from these activities is only one component of that effect; noise pollution from compressor stations is also reducing the quality of remaining forest habitat. Depending on analytical method, I found that between 31 and 83% of species considered were less abundant near compressor stations than near wellpads (Table 2.5), supporting the widespread belief that anthropogenic noise may cause birds to avoid noisy areas. Other studies, all conducted in Europe, found lower abundances near roads in 15 to 74% of species analysed (Reijnen and Foppen 1995, Reijnen *et al.* 1996, Brotons and Herrando 2001, Rheindt 2003, Peris and Pescador 2004). The three methods I used to estimate overall passerine density were consistent in their estimated noise effect size: all found a 37% reduction in passerine density at compressor sites. There did not seem to be a relationship between typical song frequency and density reduction due to noise (Tables 2.5, 2.6).

As of September 2005, there are over 5600 compressor stations in Alberta's boreal forest (IHS Energy, Calgary, AB). Compressor station clearings are typically 1 to 5 ha in size. Assuming a conservative estimate of 2 ha of cleared area per pad, 11 000 ha would be lost solely to tree removal for compressor pads in boreal Alberta (including wellpads in this estimate would drastically increase the figure). When considering the additional density reduction within 250 m of the site centroid that was observed in this study, an area of approximately 35 000 ha is impacted. The affected radius may be greater than 250 m; however, my data do not allow me to estimate this. There are many other types of noise-generating energy industry facilities, including gas plants, dehydration facilities, and pumpjacks. Adding "impacted area" buffers around other noise-generating facilities would further increase this figure. By demonstrating that noise is an issue for songbirds even when edge effects are accounted for, my results support the belief that road noise may have negative effects on songbirds. Consequently, adding busy roads to the list of noise-generating sites would dramatically increase the "impacted area" estimate.

All of the methods used to assess bird detectability and density had particular advantages and drawbacks. Nevertheless, all found bird detectability to be equivalent between compressor and control sites. This lends confidence to my methods, as it demonstrates that observers were able to hear birds sufficiently well at compressor sites to perform point counts accurately. A more in-depth spot-mapping technique

would have been a useful addition to my study (Buckland 2006); some of the detectability problems with point counts might have been resolved with such an approach. Unfortunately, a spot-mapping protocol is very expensive and highly time- and labour-intensive to implement. Uncertainty in the number of individuals detected also can occur with spot-mapping as the interpreter has to use an arbitrary set of rules to decide exactly how many individuals are present and exactly what portion of each territory is within the bounds of the sampling area. In an ideal situation, I would have compared the density estimates produced by these models to known bird densities (Farnsworth *et al.* 2002). As an alternative to point counts, line transects could have been used, but they require greater person-effort than point counts and provide fewer independent data points. Furthermore, for the purposes of this study line transects would have caused additional issues, as noise level would vary across one sampling unit.

Although some species had lower abundance near compressor stations than wellpads, Tennessee Warblers (*Vermivora peregrina*) and Yellow-rumped Warblers (*Dendroica coronata*) were exceptions; they were found in greater abundance near compressors. Both are forest generalists, meaning that they can use a wide variety of forest types but do not use open grassy habitat such as those found on a wellpad or compressor station site. Perhaps the edge conditions created by compressor stations differ from those created by wellpads in a way that benefits these species, but I have no data to support this hypothesis. Unrecorded, fine-scale vegetation features could have had a marked effect on my abundance estimates. The Yellow-rumped Warbler, for example, needs a small amount of conifer in its territory; I only accounted for overall stand type. However, both species have high-pitched songs for forest birds, with minimum frequencies >3.5 kHz (Borror and Gunn 1985; Table 2.6) and so may be less susceptible to noise effects than other species that have lower frequency songs.

2.6 Conclusions

The general trend towards reduction of density in noisy areas shows that some bird species may be able to recognize these areas as detrimental to their fitness. If birds are present in noisy areas but other processes are negatively affected, the effect on population dynamics could potentially be severe as these areas may act as population sinks. If a particular species has higher occupancy or density in noisy areas, those areas may act as ecological traps (Battin 2004). For example, I found higher densities of Tennessee Warblers and Yellow-rumped Warblers near compressor stations. If habitat conditions near compressor stations are attracting males of these species, it is possible that they may have reduced fitness in those areas due to difficulty in attracting a mate as a consequence of noise interference. This possibility is explored in the next chapter.

Table 2.1. Mean number of birds detected (and standard error) of various bird species (full species names can be found in Table 2.6). Data used in the analysis were from a series of point counts conducted in northeastern Alberta in areas of high and low chronic background noise, 2003-2004. "Treatment" refers to sites located near chronically-noisy energy industry facilities, versus control sites near similar, but noiseless, facilities. In the species column, "All Pass" refers to all passerines combined.

Point count radius:		**50 m**		**150 m**	
Species	**Treatment**	**Mean**	**SE**	**Mean**	**SE**
ALFL	Ctrl	.023	.016	.080	.029
	Comp	0	0	.078	.026
AMRO	Ctrl	.068	.027	.205	.052
	Comp	.008	.008	.055	.020
BAWW	Ctrl	.034	.019	.068	.027
	Comp	.023	.013	.070	.023
CHSP	Ctrl	.068	.031	.318	.059
	Comp	.023	.013	.164	.033
CORA	Ctrl	.023	.023	.193	.058
	Comp	0	0	.055	.023
COWA	Ctrl	.045	.022	.159	.051
	Comp	.023	.013	.039	.017
HETH	Ctrl	.023	.016	.125	.039
	Comp	.008	.008	.055	.020
LEFL	Ctrl	.273	.066	.545	.088
	Comp	.023	.013	.063	.024
MOWA	Ctrl	.011	.011	.216	.047
	Comp	.016	.011	.109	.028
OVEN	Ctrl	.523	.074	2.102	.141
	Comp	.414	.054	1.438	.093
RBGR	Ctrl	.091	.031	.409	.066
	Comp	.008	.008	.008	.008
SWTH	Ctrl	.023	.016	.250	.057
	Comp	.023	.013	.125	.031
TEWA	Ctrl	.227	.053	1.057	.118
	Comp	.352	.056	1.375	.122
VISP	Ctrl	.398	.064	1.159	.090
	Comp	.172	.035	.617	.067
WTSP	Ctrl	.091	.042	.852	.095
	Comp	.094	.032	.508	.067
YRWA	Ctrl	.080	.037	.261	.059
	Comp	.070	.025	.328	.054
All Pass	**Ctrl**	**2.000**	**.165**	**2.250**	**.187**
	Comp	**1.258**	**.104**	**1.414**	**.114**

Table 2.2. Estimated coefficients (and resulting constant) for four variables used in a generalized estimating equation analysis of densities of various bird species (full species names can be found in Table 2.6). Data used in the analysis were from a series of point counts conducted in northeastern Alberta in areas of high and low chronic background noise, 2003-2004. "Treatment" refers to sites located near chronically-noisy energy industry facilities, versus control sites near similar, but noiseless, facilities; a negative coefficient implies that particular species had lower densities in noisy areas. Vegetation is a composite variable derived from factor analysis which is positively associated with shrub cover. Shaded cells represent significant variables ($P<0.05$). In the species column, "All Pass" refers to all passerines combined.

	50-m point count radius					150-m point count radius				
	Treatment	Vegetation	Date	Time	Constant	Treatment	Vegetation	Date	Time	Constant
ALFL	-.021	.013	.002	-.110	-.260	.033	.077	.002	-.575	-.191
AMRO	-.050	.014	-.001	-.406	.395	-.091	.067	-.009	.299	1.623
BAWW	.002	.020	-.0007	.672	-.039	.016	.030	.001	.649	-.238
CHSP	-.056	-.004	.003	-.483	-.362	-.175	.018	-.001	1.08	.175
CORA	-.019	.006	-.00005	.370	-.074	-.098	.091	.003	.089	-.325
COWA	-.020	.004	.0001	.207	-.036	-.110	.029	.002	.291	-.279
HETH	-.012	.006	.0002	-.021	-.00001	-.066	.010	.0003	-.012	.078
LEFL	-.291	-.049	.006	.169	-.769	-.535	-.090	.009	.106	-.977
MOWA	.013	.022	.001	-.190	-.127	-.034	.146	.002	-.346	-.051
OVEN	-.078	-.002	-.001	1.313	.305	-.286	.032	-.002	2.203	3.068
RBGR	-.071	.020	.0001	-.007	.061	-.170	.056	-.0008	.177	.471
REVI	-.196	.112	.011	-.105	-1.445	-.406	.189	.011	-1.541	-.285
SWTH	-.005	-.011	-.0003	-.359	.177	-.121	-.050	.0006	-.384	.271
TEWA	.155	.093	.009	1.227	1.423	.334	-.062	.038	1.533	6.96
WTSP	.057	.111	.002	.158	-.271	-.129	.481	-.002	.334	.889
YRWA	-.025	-.022	.002	-.565	-.043	-.049	-.195	.005	-1.416	-.060
All Pass	**-.303**	**.254**	**.003**	**2.37**	**.768**	**-.616**	**.298**	**.006**	**1.517**	**.736**

Table 2.3. Models for a series of occupancy estimation models derived by Program MARK. Data used in the analysis were from a series of point counts conducted in northeastern Alberta in areas of high and low chronic background noise, 2003-2004. For each passerine species, eight models were evaluated and Akaike weights (w_i) were summed for all models which included a "noise treatment" parameter that affected occupancy or detection probability. This "weight of evidence" procedure allowed me to evaluate the overall importance of the treatment effect across models (Burnham and Anderson 2002). Shaded cells had $\sum w_i > 0.6$ and were considered to be significant. Also shown are best models as determined by AIC_c and their associated Akaike weights. ψ represents the occupancy rate of a site, while p represents the detection probability; g refers to a parameter varying across treatment groups, while "." refers to that parameter being constant across treatments. *Shrub* represents a principal component axis measure of vegetation which is positively correlated with shrub cover. Full species names can be found in Table 2.6.

Species	$\sum w_i(p(g))$	$\sum w_i(\psi(g))$	Best Model	Weight (w_i)
ALFL	0.358	0.31	$p(.)\ \psi(.)$ + *shrub*	0.286
AMRO	**0.791**	0.287	$p(g)\ \psi(.)$	0.413
BAWW	0.267	0.199	$p(.)\ \psi(.)$	0.371
CHSP	0.467	0.264	$p(g)\ \psi(.)$	0.275
CORA	0.295	**0.861**	$p(.)\ \psi(g)$ + *shrub*	0.609
COWA	0.453	0.373	$p(g)\ \psi(.)$	0.24
HETH	0.308	0.36	$p(.)\ \psi(.)$	0.279
LEFL	**0.921**	0.349	$p(g)\ \psi(.)$ + *shrub*	0.386
MOWA	0.471	**0.916**	$p(.)\ \psi(g)$ + *shrub*	0.449
RBGR	**0.959**	**0.632**	$p(g)\ \psi(g)$ + *shrub*	0.536
REVI	**0.951**	**0.857**	$p(g)\ \psi(g)$ + *shrub*	0.423
SWTH	0.245	0.304	$p(g)\ \psi(.)$	0.291
TEWA	0.413	**0.729**	$p(.)\ \psi(g)$ + *shrub*	0.43
WTSP	0.469	0.229	$p(.)\ \psi(.)$ + *shrub*	0.337
YRWA	0.383	0.158	$p(.)\ \psi(.)$ + *shrub*	0.455

Table 2.4. Estimated detection probabilities and densities from removal modeling following Farnsworth *et al.* (2002). Data used in the analysis were from a series of point counts conducted in northeastern Alberta in areas of high and low chronic background noise, 2003-2004. "Compressor" sites were located near chronically-noisy energy industry facilities, while "control" sites were located near similar, but noiseless, facilities. In the species column, "All Pass" refers to all passerines combined. Full species names can be found in Table 2.6.

	DETECTION PROBABILITY					DENSITY (birds/ha)				
	Compressor		Control			Compressor		Control		
Species	**Estimate**	**95% CI**	**Estimate**	**95% CI**	**Sig. Diff?**	**Estimate**	**95% CI**	**Estimate**	**95% CI**	**Sig. Diff?**
CHSP	.948	.846 - 1.050	.899	.899 - .741	N	.024	.023 - .026	.050	.045 - .055	Comp>Ctrl
CORA	.848	.418 - 1.277	.913	.913 - .735	N	.010	.007 - .014	.030	.026 - .034	Comp>Ctrl
HETH	.942	.747 - 1.136	.995	.995 - .974	N	.008	.007 - .010	.018	.017 - .018	Comp>Ctrl
LEFL	.986	.931 - 1.040	.996	.996 - .988	N	.009	.009 - .009	.077	.077 - .078	Comp>Ctrl
MOWA	.965	.878 - 1.053	.921	.921 - .768	N	.016	.015 - .017	.033	.030 - .037	Comp>Ctrl
OVEN	.919	.801 - 1.036	.954	.954 - .887	N	.221	.201 - .241	.312	.296 - .328	Comp>Ctrl
RBGR	1.000	1.000 - 1.000	.976	.976 - .936	N	.001	.001 - .001	.059	.058 - .061	Comp>Ctrl
REVI	.969	.935 - 1.002	.856	.856 - .508	N	.090	.088 - .092	.192	.134 - .250	Comp>Ctrl
SWTH	.992	.968 - 1.016	.967	.967 - .899	N	.018	.017 - .018	.037	.035 - .038	Comp>Ctrl
TEWA	.984	.972 - .997	.966	.966 - .932	N	.198	.196 - .199	.155	.151 - .158	Ctrl>Comp
WTSP	.966	.926 - 1.006	.845	.845 - .466	N	.074	.072 - .077	.143	.098 - .187	Comp>Ctrl
YRWA	.943	.865 - 1.021	.920	.920 - .777	N	.049	.046 - .052	.040	.037 - .044	Ctrl>Comp
All Pass	**.923**	**.869 - .977**	**.919**	**.861 - .977**	**N**	**.879**	**.843 - .914**	**1.377**	**1.315 - 1.439**	**Ctrl>Comp**

Table 2.5. Summary of results from four analysis methods conducted to assess passerine densities in the presence of chronic industrial background noise. Data were collected using point counts in northeastern Alberta, 2003-2004. "Compressor" sites were located near chronically-noisy energy industry facilities, while "control" sites were located near similar, but noiseless, facilities. In the table, "Ctrl" represents significantly higher densities (or occupancy rate) found at control sites ($P<0.05$); "Comp" represents the opposite. "-" means that the analysis could not be conducted for that species for statistical reasons. In the species column, "All Pass" refers to all passerines combined. "Prop. reduced" is the proportion of species analysed which showed significant density or occupancy reductions at compressor sites. Full species names can be found in Table 2.6.

Species	Generalized Estimating Equation (50-m radius)	Generalized Estimating Equation (150-m radius)	Occupancy Estimation	Removal Modeling
ALFL				-
AMRO	Ctrl	Ctrl		-
BAWW				-
CHSP	Ctrl	Ctrl		Ctrl
CORA			Ctrl	Ctrl
COWA				-
HETH				Ctrl
LEFL	Ctrl	Ctrl		Ctrl
MOWA			Ctrl	Ctrl
OVEN		Ctrl	-	Ctrl
RBGR	Ctrl	Ctrl	Ctrl	Ctrl
REVI	Ctrl	Ctrl	Ctrl	Ctrl
SWTH		Ctrl		Ctrl
TEWA			Ctrl	Comp
WTSP				Ctrl
YRWA				Comp
All Pass	**Ctrl**	**Ctrl**	**-**	**Ctrl**
Prop. reduced	**0.31**	**0.44**	**0.33**	**0.83**

Table 2.6. Common and scientific names for bird species used in analysis for a study on the effects of chronic industrial noise on birds in northern Alberta, Canada. Approximate song frequency ranges are from Borror and Gunn (1985) and Birds of North America Online (Cornell University, Ithaca, NY).

Abbreviation	Common name	Scientific name	Song frequency range (kHz)
ALFL	Alder Flycatcher	*Empidonax alnorum*	1.8 – 6.4
AMRO	American Robin	*Turdus migratorius*	1.5 – 5
BAWW	Black-and-white Warbler	*Mniotilta varia*	6 – 9
CHSP	Chipping Sparrow	*Spizella passerina*	3 – 7.5
CORA	Common Raven	*Corvus corax*	0.4 – 8
COWA	Connecticut Warbler	*Oporornis agilis*	2 – 6.5
HETH	Hermit Thrush	*Catharus guttatus*	1.5 – 7
LEFL	Least Flycatcher	*Empidonax minimus*	3 – 12
MOWA	Mourning Warbler	*Oporornis philadelphia*	2 – 7
OVEN	Ovenbird	*Seiurus aurocapilla*	2.2 – 7
RBGR	Rose-breasted Grosbeak	*Pheucticus ludovicianus*	3 – 9
REVI	Red-eyed Vireo	*Vireo olivaceus*	1.5 – 8.5
SWTH	Swainson's Thrush	*Catharus ustulatus*	1 – 5
TEWA	Tennessee Warbler	*Vermivora peregrina*	4 – 10
WTSP	White-throated Sparrow	*Zonotrichia albicolis*	2.1 – 4.7
YRWA	Yellow-rumped Warbler	*Dendroica coronata*	3.5 – 7

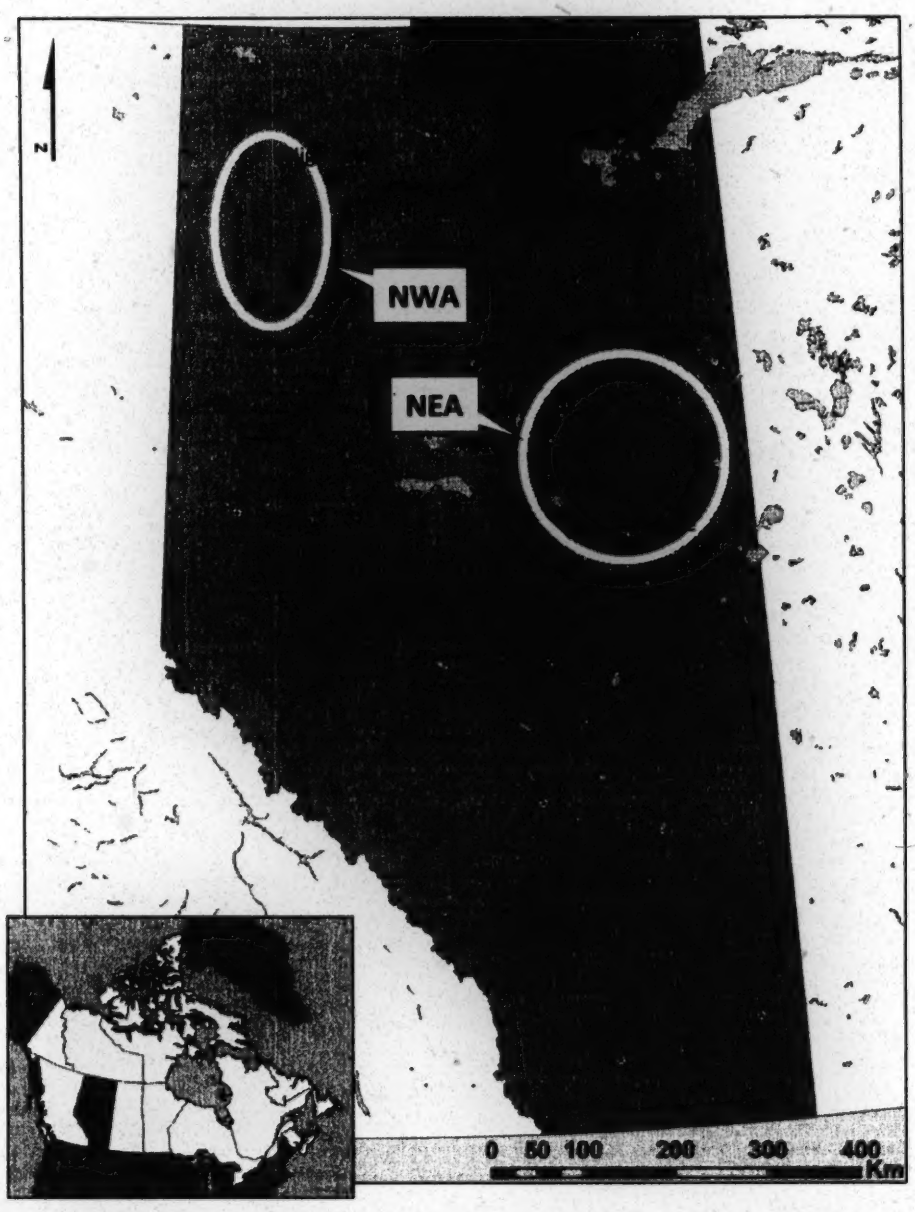

Figure 2.1. Map of the two study areas located in northern Alberta, Canada, for a study on the effects of chronic industrial noise on birds. Point counts were conducted in the northeastern study area (NEA) in 2003 and 2004.

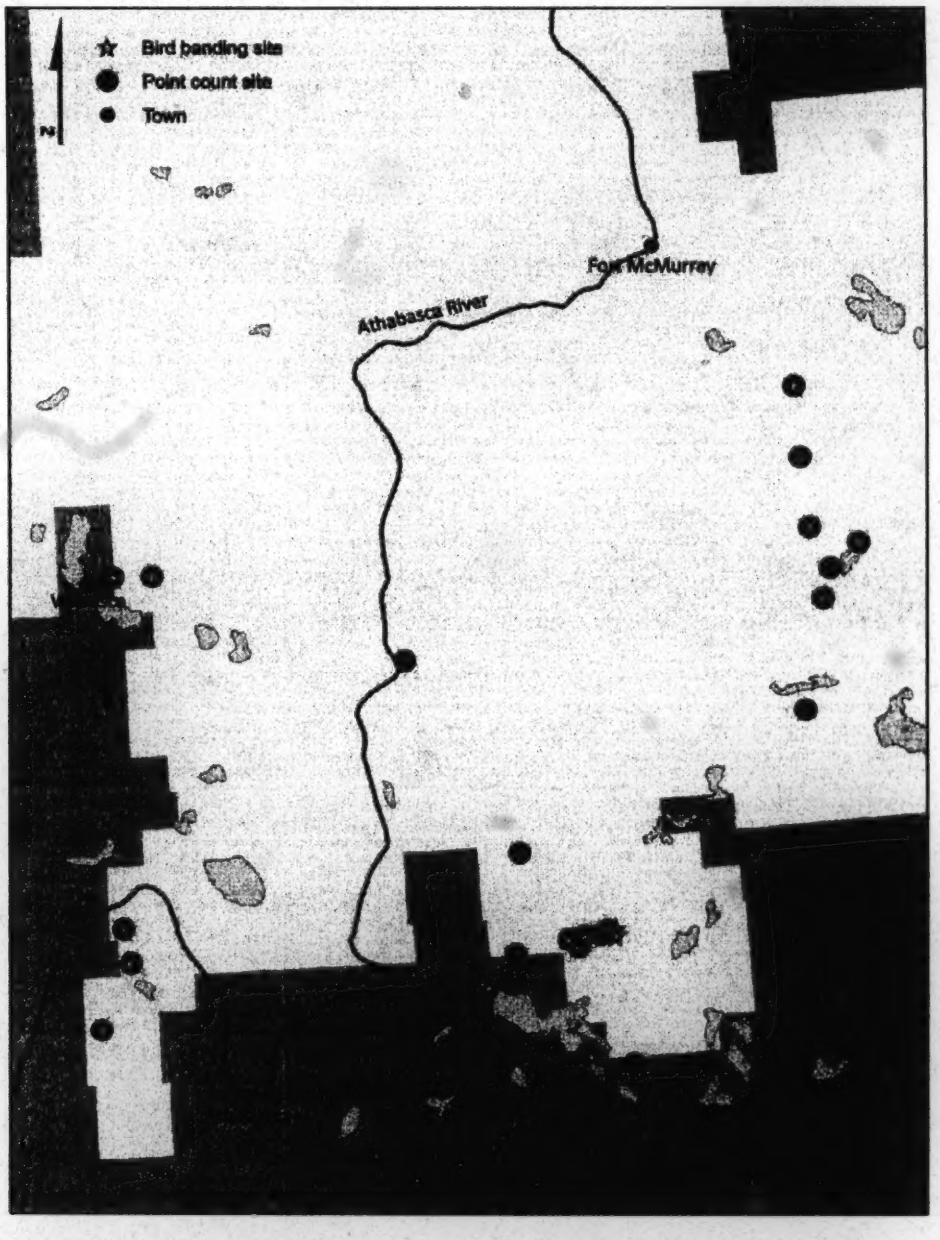

Figure 2.2. Map of the northeastern study area (NEA) located in northern Alberta, Canada. The study on the effects of chronic industrial noise on bird abundance and occupancy was conducted in the area in 2003 and 2004, while the Ovenbird pairing success study was conducted there in 2004. The Alberta-Pacific Forest Industries, Inc. Forest Management Agreement is shown in the lighter shade.

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CHAPTER 3. EFFECTS OF CHRONIC INDUSTRIAL NOISE ON OVENBIRD PAIRING SUCCESS AND AGE STRUCTURE

3.1 Introduction

Density or relative abundance is not necessarily the best metric by which to assess the status of a population because it may not always be accurate predictors of habitat quality (Van Horne 1983). Reduced habitat quality may instead manifest itself in other, subtler ways such as reduced pairing success, higher stress levels, reduced survival, or altered age structure. Van Horne (1983) suggested that this density-habitat quality disconnect is most likely to occur under either of two conditions: 1) when a population size has been determined at a time or place other than that at which it was estimated, or 2) when dominant individuals secure prime habitats, forcing lower-ranking animals to inhabit more marginal areas. Bock and Jones (2004) suggest a third condition under which this effect may be observed: when anthropogenic disturbance impairs the animal's ability to correctly assess and inhabit optimal habitats. While the first condition does not apply in the case of noise effects, the second may and the third certainly do. These effects may negatively impact reproductive parameters or ultimately, population persistence. In this chapter, I assess whether pairing success and age structure may be impacted by chronic industrial background noise, using the Ovenbird as a model species.

3.1.1 Pairing success

Many factors contribute to the ability of male birds to pair with a female during the breeding season. These include age, size, body condition, and the quality of the territory selected by the male (Breitwisch 1989). Recent research suggests that the conditions required to maximise male pairing success are often reduced in areas of high human influence, particularly those areas impacted by forest fragmentation (Villard *et al.* 1993, Reijnen and Foppen 1994, Van Horn *et al.* 1995, Lambert and Hannon 2000, Bayne and Hobson 2001). While the vast majority of pairing success studies have examined direct impacts of human activity on habitat, it is possible that non-physical anthropogenic impacts may also diminish the ability of male birds to attract females.

As birds communicate primarily by sound, loud ambient noise caused by human activities could inhibit communication between conspecifics, thereby reducing pairing success. Birds in forests typically have songs characterized by low frequencies (2.5-4.0

kHz). These frequencies provide optimal long-distance song transmission range in complex forest structure (Brenowitz 1982, Slabbekoorn *et al.* 2002). As a result, much birdsong lies in the same part of the frequency spectrum occupied by many types of mechanical noise (Binek 1996, ATCO Noise Management 2003); because of this overlap, industrial noise may interfere with bird communication occurring via song. If the ability to effectively communicate with females is influenced by anthropogenic noise then we might expect that males in high-noise areas would be less likely to attract a mate.

The limited work done in the area of chronic noise and wildlife has mostly examined the effects of traffic noise on bird populations near highways. Many species of birds exhibit reduced breeding densities in areas around roads, with noise assumed to play a larger role in that reduction than visibility of cars or traffic mortality (Reijnen *et al.* 1995, Kuitunen *et al.* 1998). Some bird species have been shown to also have reduced *breeding* success (*i.e.* a lower probability of mating and successfully rearing young) near roads (Reijnen and Foppen 1994, Burke and Nol 2000, Kuitunen *et al.* 2003). However, it has never been conclusively demonstrated that the noise generated by roads is the factor that results in reduced breeding success in birds.

3.1.2 Ovenbird age

A growing body of evidence suggests that the age of breeding males in an area may be an indicator of habitat quality. For example, older Black-throated Blue Warbler (*Dendroica caerulescens*) males occupy higher-quality sites than do younger males (Holmes *et al.* 1996). Furthermore, Holmes *et al.* (1996) cite evidence that older males also selected the best quality areas – in this case, the shrubbiest ones –*within* high-quality habitat. However, as they also found more paired birds in better habitat, and found that most unpaired birds were younger, there is evidence of a three-way interaction between age, pairing success, and territory quality.

Although the mechanisms causing age biases by habitat are not clear, it is possible that older and more experienced males secure the highest-quality habitat, possibly because they return from migration first (Holmes *et al.* 1996). This forces younger males to choose territories in suboptimal habitat. The consequence of this "ideal-despotic" behaviour in socially monogamous species with a male sex bias is that females may be less likely to be found in suboptimal habitats than males (Krebs 1971, Sherry and Holmes

1989). Additionally, evidence suggests that even in good-quality habitat, younger male birds have lower pairing success than older males due to selection by females for older individuals (Sæther 1990, Bayne and Hobson 2001). The consequence of such behaviours seems to be reduced reproductive output in areas with a high proportion of young birds relative to the preferred habitat (Holmes *et al.* 1996, Zanette 2001). If noise creates lower-quality habitat, we would expect this increase in younger males to be observed near compressor stations. In a landscape with rapidly-expanding industry and its associated noise, this reduction in habitat quality could have implications for population persistence.

Male quality as measured by age and body morphology has been shown to be an important determinant of pairing success in other studies (Sæther 1990, Bayne and Hobson 2001). If there is no effect of noise on Ovenbirds, then *a priori* I predicted that there should be no differences in age structure or body morphology of birds between compressor and control sites. However, if noise does affect pairing success it may do so by influencing the quality of the individuals that settle at compressor versus control sites.

Overall, the objectives of this chapter were to 1) assess if pairing success of male Ovenbirds is affected by the presence of chronic industrial background noise, and 2) determine if the age distribution of male Ovenbirds is consistent between noisy and quiet areas.

3.2 Study Area

3.2.1 Location

This research was conducted in two areas in northern Alberta (Figure 2.1). The northeastern study area (NEA), used in 2004 and described in §2.2.1, was located within the Alberta-Pacific Forest Industries Inc. (ALPAC) Forest Management Area (FMA). The northwestern study area (NWA), used in 2005, was located within the Tolko Industries and Daishowa-Marubeni International Ltd. (DMI) FMAs (Figure 3.1). In terms of vegetation, the NWA has a greater proportion of upland mixedwood than the NEA (Strong and Leggat 1992).

3.2.2 Site selection

I defined two sets of sites at which the project was carried out – compressor sites and control sites, as described in §2.2.2. To reiterate, the only major difference between the compressor sites and control sites was that the compressor sites had a noise-generating facility while the controls did not. Alberta Vegetation Inventory data for the NWA was provided by DMI and Tolko.

3.3 Methods

3.3.1 Ovenbird capture

In spring 2004 and 2005, male Ovenbirds were captured in the NEA and NWA study sites respectively. Sites selected had the same accessibility and vegetation cover criteria as expressed in §2.3.1. One additional criterion was implemented; all sites had enough aspen cover to have the potential to capture 4 Ovenbirds in non-adjacent territories; we aimed to capture one on each side of the clearing polygon (see below for methodology; Figure 3.2).

Birds were captured in approximately equal numbers at compressor sites and control sites (site categories as described in chapter 1). Hereafter, these will be known as "compressor birds" and "control birds", respectively. All captures were conducted between 24 May and 22 June. The majority of birds were captured before 9 June; birds captured after that date were usually replacements who had assumed the territory of birds we had banded, but had vacated the area post-capture. These "missing" birds were presumed not to have permanently settled in the territory; they were excluded from all analyses. Capture attempts were focused on the early morning (0400-1000 MDT) but during the peak capture period birds were caught at all times of day.

To locate birds to potentially band, we walked the perimeter of a cleared site listening for male Ovenbirds singing near the forest's edge. If an Ovenbird was heard, and estimated to be <200 m from the clearing edge, we targeted it for capture. If during a walk of the perimeter no Ovenbirds were heard, we repeated the walk while playing recordings of male Ovenbird songs from speakers. Locating birds by playback may result in birds moving closer to the edge than they would have been found otherwise;

however, it is safe to assume that Ovenbirds responding to the playback of a rival male's song would remain within the boundary of their territories. Therefore, all birds caught were likely the closest inhabitants to the edge.

Once a bird had been targeted for capture, we approached the location from which it was calling and set up a mist net (usually 6 m in length, occasionally 12 m). We attempted to position the net near low shrubs or a small conifer. The playback device was placed near the centre of the net, either on the ground or suspended from a sturdy branch. One of three songs was placed on repeat to draw the bird into the net; the song recording being played was sometimes changed depending on the response of the bird. If the bird proved difficult to capture – we spent up to one hour on some individuals – we would abandon it and make another capture attempt at a later date.

Once captured, birds were sexed based on the presence of a cloacal protuberance and lack of a brood patch (Pyle *et al.* 1987). Each bird received a U.S. Fish and Wildlife Service aluminium band and three coloured-plastic leg bands to form a unique band combination. We measured unflattened right wing chord (mm), tail length (mm), right tarsal length (mm), and mass (g) of each bird (after Pyle *et al.* 1987). We derived a condition index by dividing mass by wing chord (Burke & Nol 2001). We also plucked the third right rectrix in order to age the bird (details in §3.3.3). Following the procedure, the bird was released away from the net; pairing observations on the bird did not commence until at least the next day.

3.3.2 Pairing observations

Each banded Ovenbird was followed in order to determine whether or not it successfully paired with a female. My observation protocol followed those of Lambert and Hannon (2000) and Bayne and Hobson (2001). Birds were followed for up to 90 minutes over the breeding season, or until a sign of pairing was observed. Signs of pairing included observing: (1) the male in the vicinity of a female; (2) the male carrying food; (3) the male or female with nesting material; (4) the male or female with young; or (5) an active nest within the male's territory (Bayne and Hobson 2001). As Ovenbirds are monomorphic, a non-singing individual tolerated by a male within a 5 m radius or emitting a series of "*tsip*" notes was considered its female mate, as females often make those vocalisations in response to their mate's song (Lein 1980).

Birds were tracked for a maximum of 30 minutes per day, with "track time" being accumulated when the bird was in sight or in continuous song within 30 m of the observer. Tracking days were spread out over the breeding season; all efforts were made to have a minimum of one 30-min tracking period during the prime courting and nest-building period (~27 May – 9 June), as this is the best time to determine pairing status. For birds who were not determined to be paired before ~9 June, a second tracking period was attempted during the females' nesting period when the male is feeding the young (until ~19 June), and a third after the chicks had left the nest (beginning ~20 June).

3.3.3 Ovenbird age

By measuring the tip angle of the third right rectrix, it is possible to classify an Ovenbird as either a second-year (SY) bird or an after-second-year (ASY) bird (Donovan and Stanley 1995). SY birds are breeding for the first time, while ASY birds were potentially breeding the year before. Ageing birds in this manner is possible because Ovenbirds retain their juvenile tail feathers through their first winter season and do not moult them until after their first breeding season (Pyle *et al.* 1987). These feathers are often tapered, compared to the paddle shape of post-moult rectrices present in ASY individuals (Pyle *et al.* 1987; Figure 3.3).

Feathers were digitally scanned into a computer and images were expanded by a constant size. Images were printed in greyscale and the angle of the feather tip calculated using transparent grid paper, a small ruler, and the Pythagorean Theorem. Birds with a rectrix tip angle of <84° were classified as SY; those with tip angles >84° were classified as ASY (Bayne and Hobson 2001; Figure 3.3). All feathers were classified blindly by bird ID number without knowledge of what treatment group that individual was from.

3.3.4 Territory vegetation measurements

I conducted a vegetation survey in the territory of each banded male Ovenbird. Vegetation parameters measured were determined to have relevance to Ovenbird territory quality by Mazerolle & Hobson (2002). We conducted four 1-m wide, 25-m long transects oriented along a random bearing. Transects were spaced 10 m apart and were placed around the centre of the territory (Figure 3.4). We measured diameter at breast height (DBH) of all trees that intercepted a transect. I used a "bird-centric" definition of "tree": any vegetation >5 m in height was classified as a tree, and all stems emerging

from the same individual plant were measured separately. While walking the transects, I recorded the number of downed woody material (DWM) pieces the transect intercepted.

Along each transect, five 0.25-m^2 plots were placed at 5-m intervals (Figure 3.4). In each plot, I measured shrub species, density (number of stems of each species), and height category (0.5 to 2 m or >2 m). I also measured the leaf litter depth at the centre of each plot with a metal metre stick, and estimated percent cover of forbs, moss, and grass in each plot using the same five cover categories as discussed in §2.3.2. For analysis, all vegetation measurements were averaged for each Ovenbird's territory. Shrub density and height were transformed into two variables – density of short shrubs and density of high shrubs. Tree data were used to obtain the average DBH for each territory, as well as density of each tree species and density of hardwood and softwood.

3.3.5 Statistical analysis

To evaluate whether Ovenbirds at compressor sites had lower pairing success than at control sites, I used a GEE with a binomial error structure and a logit link within STATA 9.1. Within the GEE framework, the pairing status of the multiple birds sampled at each site is assumed to be correlated to an extent that is estimated by the model (Hardin and Hilbe 2003). By estimating the exchangeable correlation in pairing status of individuals within the same site, estimates of standard errors are robust to any lack of independence. *A priori* I predicted that noise would reduce pairing success so my tests for noise effects were all one-tailed. All birds which had gone missing (n=35), or whose pairing status was undetermined (n=3), were excluded from analyses.

This experiment was designed to minimise any variation in habitat quality due to vegetation structure. However, variation in habitat quality for attributes that are not effectively described by AVI data could have been a confounding factor in my design. To control for any vegetation effects, I used principal components analysis (PCA) in STATA 9.1 to summarize the variation in vegetation structure for all territories. All vegetation variables were standardized to zero mean and unit variance prior to PCAs. PCA of DWM, forb cover, moss cover, grass cover, litter depth, high shrub density, low shrub density, hardwood tree density, and softwood tree density resulted in two principal component axes that together explained 40% of the variation in the original data set. The first factor represented territories with large trees, higher shrub density, and more DWM

(positive loading on component 1 – hereafter "territory structure"). The second factor represented territories that varied in the proportion of deciduous to conifer trees (positive loading for deciduous tree density – hereafter "territory composition"). Territory structure and territory composition were included in my GEE model to ensure that any confounding effects of vegetation structure as a measure of territory quality were controlled for when assessing the effects of noise. As vegetation factors were simply nuisance variables with no *a priori* predictions as to direction I report their statistical significance as two-tailed tests.

A GEE was used to test whether the frequency of occurrence of old versus young birds differed between the two treatments. We also tested whether bigger birds, or those in better condition, were less likely to settle at compressor versus control sites A GEE was used to analyze these data with respect to noise treatment. In this analysis I assumed a Gaussian error structure and identity link. Vegetation structure within territories was controlled for in all analyses. *A priori* I predicted that larger and older birds would be more likely to settle at controls than at compressors so all statistical tests are one-tailed.

All results are reported as odds-ratios (hereafter OR) or slope coefficients (β). Statistical tests are reported as z-scores from GEEs unless otherwise reported, with probability values derived as discussed above. All tests had degrees of freedom of 1 and are considered significant at P=0.05.

3.4 Results

3.4.1 Pairing success

A total of 148 birds were captured over the 2004 and 2005 breeding seasons. Data were pooled across years for all analyses. Summary data are presented in Table 3.1. As mentioned in §3.3.5, all birds which had gone missing and were not relocated (n=35) were excluded from all analyses. A contingency table analysis with a chi-squared test demonstrated no significant difference in the number of birds who went missing between the two treatments (χ^2=0.77, P=0.38). There was also no difference in the number of birds who went missing between the two age categories (χ^2=1.76, P=0.18).

We were unable to amass 90 minutes of pairing observations, or observe a conclusive pairing sign, on 3 birds (2 control birds, 1 compressor bird). In these cases, we were certain that the birds were still present in the territory (we would obtain ephemeral glimpses of their bands), but they were very difficult to follow and observe. These birds were also excluded from analyses. By far, the most common pairing sign we observed was the male walking with a female early in the breeding season.

For the remaining 110 birds we assessed 92% of control birds as paired compared to 77% of compressor birds (Table 3.2). Controlling for territory structure and composition, I found that pairing success was significantly lower for compressor birds than control birds (OR=0.31, z = -2.11, P=0.02). Territory structure was also a significant predictor of pairing success (OR=1.49, z =2.2, P=0.03), while territory composition was not (OR=0.87, z = -0.63, P=0.53). The within-site correlation was r=-0.12.

3.4.2 Ovenbird age

Age was determined for 111 Ovenbirds, excluding the missing birds, as rectrices were not plucked for two birds (n_{comp}=54, n_{ctrl}=57). At control sites, 70% of birds were classified as ASY, compared to 52% at compressor sites. A three-way contingency table analysis found that proportion of ASY birds was significantly higher at control sites than compressor sites (G=3.73, P=0.05; Table 3.2). For birds whose pairing status was determined (n=108), there was a significant difference in age structure between treatments (OR=0.50, z = -1.68, P=0.05). The within-site correlation was very low at r=0.001.

3.4.3 Body morphology and condition

Estimates of wing length, tail length, and mass were available for 107 individuals for whom pairing success was determined. No significant difference in body condition was found between compressor and control sites for those birds (β=-0.17, z=-1.38, P=0.09). There was no relationship between bird age and tail length (β=0.94, z=1.44, P=0.07), mass (β=0.12, z=0.55, P=0.29), or body condition (β=.01, z=0.95, P=0.17), although wing chord was significantly larger in older birds (β=1.09, z=2.48, P=0.007). After

controlling for age, there was no significant difference in any of the four variables between compressor and control sites.

3.4.4 Individual quality vs. habitat quality

A model containing habitat structure, habitat composition, noise status, individual age, and individual morphology was also created to determine the relative importance of individual quality versus habitat quality as factors influencing pairing success. In this model, there was a significantly higher probability of pairing at control sites (OR=0.31, z=-2.1, P=0.02) and in territories with more structural complexity (OR=1.53, z=2.3, P=0.02).

3.5 Discussion

3.5.1 Pairing success

Competition to attract females seems to be intense for male Ovenbirds across their range, as nearly all studies have found pairing success to be <100% (e.g. Villard *et al.* 1993, Van Horn *et al.* 1995, Lambert and Hannon 2000, Bayne and Hobson 2001). This indicates that a biased sex ratio exists in Ovenbird populations which seems to result in strong selection by females for high-quality males or males with high-quality territories. My results suggest that females selected high quality territories rather than older or larger males. Noise level from industrial activity seems to be one habitat factor that females use when deciding how to choose a mate, as I found a 15% difference in pairing success between Ovenbirds at sites with industrial background noise and those without. This implies that intersex Ovenbird communication is being reduced by chronic background noise, leading to reduced probability of male-female mating encounters. If noise interferes with a male's song, females may either: 1) not hear the male's song at as great a distance, thereby reducing the number of females who may potentially respond to his song, and/or 2) perceive males as being of lower quality than they actually are due to the distortion of song characteristics.

While no previous work has been done on the specific issue of noise and bird pairing success, research comparing Ovenbird pairing success in extensive versus

fragmented forest has found differences in pairing success ranging from 10 to 50% (Villard *et al.* 1993, Van Horn *et* al. 1995, Bayne and Hobson 2001). The difference of 15% found in this study is at with the low end of this range. This is a biologically-significant difference since even small reductions in pairing and nesting success can have large biological effects such as a decrease in the number of floater (*i.e.* non-territorial) males or reduced return rates in subsequent years (Donovan *et al.* 1995, Porneluzi and Faaborg 1999, Burke and Nol 2001, Bayne and Hobson 2001).

Habitat quality and its effects on pairing success seem to be localised in the study area. The small negative correlation I observed within sites indicates that there was a weak tendency for birds at a site to be unpaired if other birds at that site were paired. Had females entirely avoided certain sites I would have expected a strong, positive correlation. Instead, I found that about one male per site tended to be unpaired. Why one individual was less prone to attract a mate is not entirely clear as the pairing status of these males was not influenced by their body morphology or age. One possibility is that at compressor sites the unpaired males existed at the noisiest location at that site, leading females to avoid him in preference of the other males. Admittedly however, the small sample size of unpaired males makes age and body morphology effects difficult to detect. An alternative explanation is that unpaired males had songs with characteristics that were more strongly affected by industrial noise.

Vegetation structure in territories of paired versus unpaired birds played a role in describing male pairing success. Pairing success increased in areas with more complex territory structure. While Howell *et al.* (2000) found a negative association of Ovenbird density with tree DBH, Van Horn and Donovan (1994) state that Ovenbirds prefer habitats with large trees. This discrepancy likely comes from different definitions of "larger trees", as studies in Missouri have found mean tree size is greater in territories of paired than unpaired males (Van Horn and Donovan 1994). Van Horn and Donovan (1994) emphasized the importance of litter depth in determining pairing success. Litter depth was not a significant factor determining pairing success in this study (t=-1.04, df=108, P=0.30). This may have been due to a profusion of food for the birds in the study area. In 2005 a large portion of the NWA was undergoing an outbreak of Forest Tent Caterpillar (*Malacosoma disstria* Hubner). The caterpillars and their instars provide abundant food for some warblers (Van Horn and Donovan 1994, M. Glasgow, pers.

comm.); on numerous occasions we saw Ovenbirds with them in their mouths. Leaf litter appears to be a weak determinant of pairing success for the 2004 birds, who were not located in a caterpillar-infested area (t=-1.78, df=72, P=0.08).

Habitat structure can influence the transmission of sound (Huisman and Attenborough 1991), so it is possible that birds with territories that have more habitat complexity are less impacted by noise due to greater attenuation. If this were the case I expected the interaction between habitat structure and noise treatment to be significant. In unreported analyses, I found no evidence for this (OR=0.69, z=-0.54, P=0.59) but a limited sample size of unpaired males restricted my power to detect such an effect.

At the individual level, I found no evidence that age or body morphology influenced pairing success. This is in contrast to previous work which has shown that older birds have greater pairing success than younger birds (Sæther 1990, Bayne and Hobson 2001). A connection between age and status in the presence of noise was found by Reijnen and Foppen (1994): within 200 m of a highway, young male Willow Warblers (*Phylloscopus trochilus*) were 25% less successful at attracting mates than older males, while farther from the road there were no differences in pairing success between age classes. This pattern could be explained by older birds being more experienced singers, which females may be attracted to despite the background noise.

Villard *et al.* (1993) proposed two applicable hypotheses that could account for the observed reduction in pairing success: (1) female Ovenbirds select sites with high male density (conspecific-attraction hypothesis), and (2) females prefer ASY birds to SY birds (mate-selection hypothesis). To these two hypotheses I add a third: intersex Ovenbird communication is inhibited by the chronic background noise, leading to reduced probability of male-female mating encounters (noise-interference hypothesis). If noise negatively interferes with a male's song, females may either: (1) not hear his song at great distances, thereby reducing the number of females who may potentially respond to his song, or (2) perceive him as being of lower quality than he actually is due to distortion of his song.

Regardless of which of these three hypotheses best describes the observed reduction in pairing success, noise remains the root cause. The design of this experiment ensured that I accounted for possible confounding factors such as edge effects. As well,

vegetation differences were assessed and found to be not significant. Therefore, noise was isolated as the likely cause of any effects on the breeding ecology of Ovenbirds.

3.5.2 Ovenbird age

Although I did not find an effect of individual age on pairing success, I did find that the age structure of Ovenbirds near compressor sites was different from controls overall; I observed an 18% increase in the number of young birds at compressor sites relative to control sites. This is consistent with my hypothesis that noise creates lower-quality habitat; skewed age ratios are often observed when comparing low- to high-quality habitat, as older birds force younger birds into suboptimal habitat (Krebs 1971, Van Horne 1983, Sherry and Holmes 1989, Bock and Jones 2004). How biased age structures form between habitats is not clear. Holmes *et al.* (1996) suggested that older Black-throated Blue Warbler (*Dendroica caerulescens*) males occupy higher-quality sites than do younger males by claiming the highest quality territories early in the breeding season, and thereby forcing younger males to use suboptimal sites. Older males also had higher pairing success (Holmes *et al.* 1996). My expectation was that this difference in age structure would explain the differences in pairing success I observed. Lack of a direct relationship between age and pairing success at the individual level could be the result of the limited number of unpaired males available to test for age effects and/or inaccuracies in ageing some of the birds. More work is required to test the generality of age-related variation in habitat selection in forest songbirds.

One prediction from this type of ideal-despotic behaviour (Holmes *et al.* 1996) is that sites that are high quality will tend to be reoccupied in subsequent years by males that return to sites where they were previously successful. I attempted to assess if young or unsuccessful breeders from 2004 would return to the same territory in 2005. This would have provided an indication if birds move away from noisy territories when settling the following year. In the first week of June 2005, we returned to all NEA locations where Ovenbirds were captured in 2004. Using playbacks to attract the birds in the forested periphery of the cleared site where they had been caught the preceding year, we attempted to determine if there was a difference in return rate to the control versus compressor sites. However, only one bird was re-sighted in 2005, at a compressor site. This low return rate is in distinct contrast to work by Porneluzi and Faaborg (1999),

Burke and Nol (2001), and Bayne and Hobson (2002), who found that ~40% of male Ovenbirds return to the same territory from year to year in contiguous forest. One explanation for this extremely low return rate could be that Ovenbirds at wellpads and compressor stations were universally affected by some other factor (*e.g.* high predation at edges) and subsequently never returned to either one of these anthropogenically disturbed areas. This phenomenon warrants further study.

If the pattern of age-related habitat selection were to manifest itself in females, the implications for Ovenbird population dynamics could be even more substantial. Young birds attempting to breed for the first time often have lower reproductive success (*i.e.* nest success is lower, clutch size is smaller, and overall juvenile recruitment reduced) than older individuals with previous breeding experience. In areas where young birds are dominant, population sinks may develop. Populations in sink habitats may only persist via immigration from other areas with lower levels of human disturbance. Managers should recognize that the presence of birds like the Ovenbird near compressor sites and other industrial sites does not necessarily indicate that local populations are self-sustaining.

3.6 Conclusions

With the expansion of industry, physical reduction of habitat as well as reduced breeding success in areas impacted by industrial noise could result in a large decrease in the amount of high-quality breeding habitat available for Ovenbirds and other passerines. This establishes the possibility that large parts of the boreal forest may become reproductive sinks for Ovenbirds. Many of the principles discussed in §2.5, such as "impacted area" estimates, also apply to areas in which density may not be affected but where other population parameters might.

A negative relationship between density and reproduction rates has been observed to be most common in western North America, at an intermediate level in eastern North America, and least common in Europe, implying that with increasing time since anthropogenic disturbance birds are able to adapt to the changes in their environment (Bock and Jones 2004). As boreal Alberta is a region that has only been exposed to intense anthropogenic disturbance within the last 30 years, it is likely that avifauna have

not had sufficient time to adapt to those changes. In Chapter 4, I test whether some species of boreal songbirds are able to alter the structure of their song in order to be better heard above industrial noise.

Table 3.1. Summary of male Ovenbirds captured and banded per treatment per year, and the number of birds on which pairing observations were made. "Compressor" sites had a noise-generating compressor station at the centre of a forest clearing, while "control" sites had a noiseless wellhead at the centre. The study was conducted in northern Alberta in 2004 and 2005.

	2004		2005		Total # of Birds Observed (Captured – Missing)
	Captured	Missing	Captured	Missing	
Control	47	8	26	7	58
Compressor	44	7	31	13	55
Total	**91**	**15**	**57**	**20**	**113**

Table 3.2. Contingency table illustrating Ovenbird pairing success and age distribution between treatments. SY birds are first-year breeders, while ASY birds are in at least their second breeding season. "Compressor" sites had a noise-generating compressor station at the centre of a forest clearing, while "control" sites had a noiseless wellhead at the centre. The study was conducted in northern Alberta in 2004 and 2005.

Status →	**Paired**		**Unpaired**		
Treatment →	Compressor	Control	Compressor	Control	**Total**
Age ↓					
SY	20	17	6	0	**43**
ASY	23	34	4	4	**65**
Total	43	51	10	4	**108**

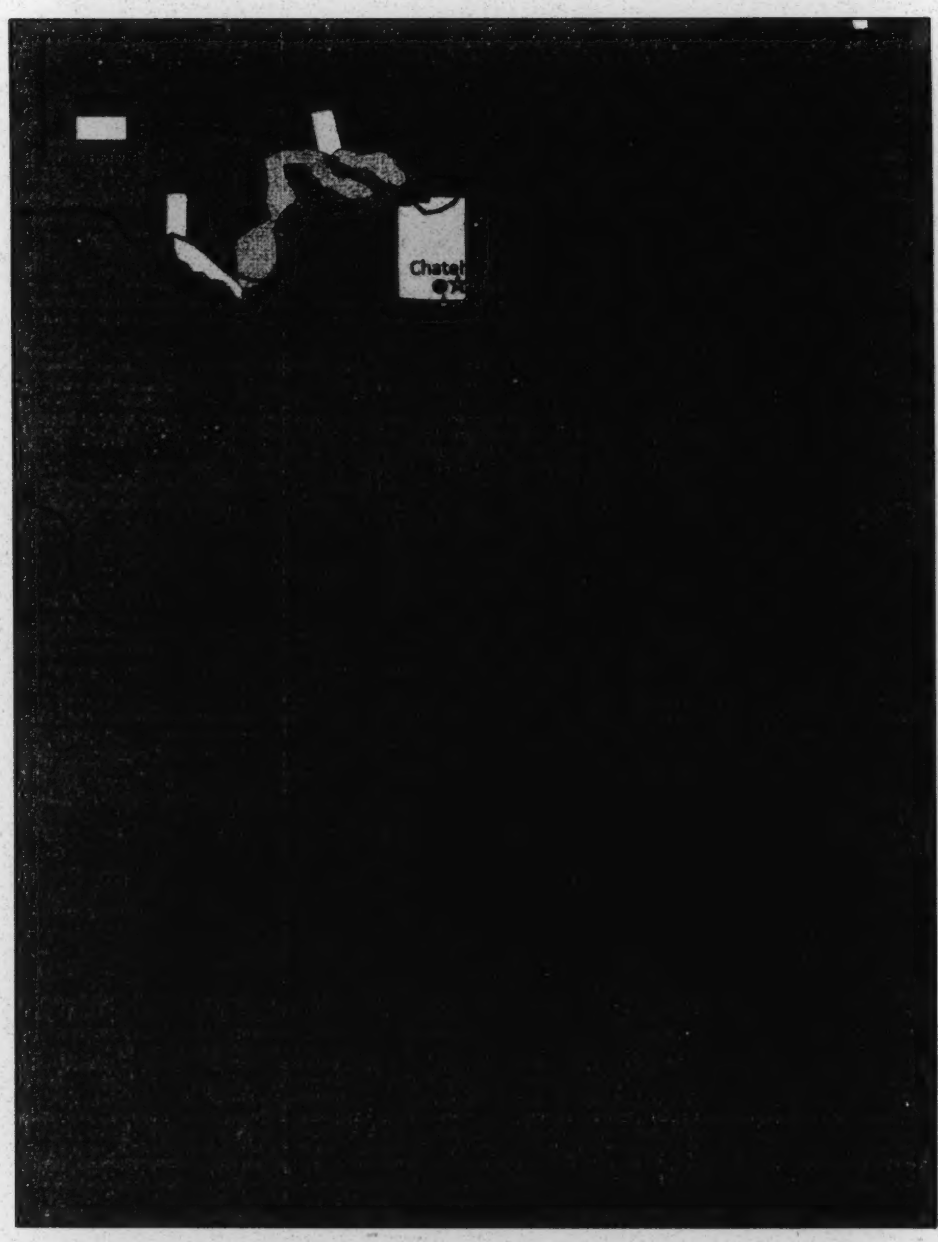

Figure 3.1. Map of the northwestern study area (NWA) located in northern Alberta, Canada. The study on the effects of chronic industrial noise on Ovenbirds was conducted in the NEA in 2004 (Figure 2.2) and in the NWA in 2005.

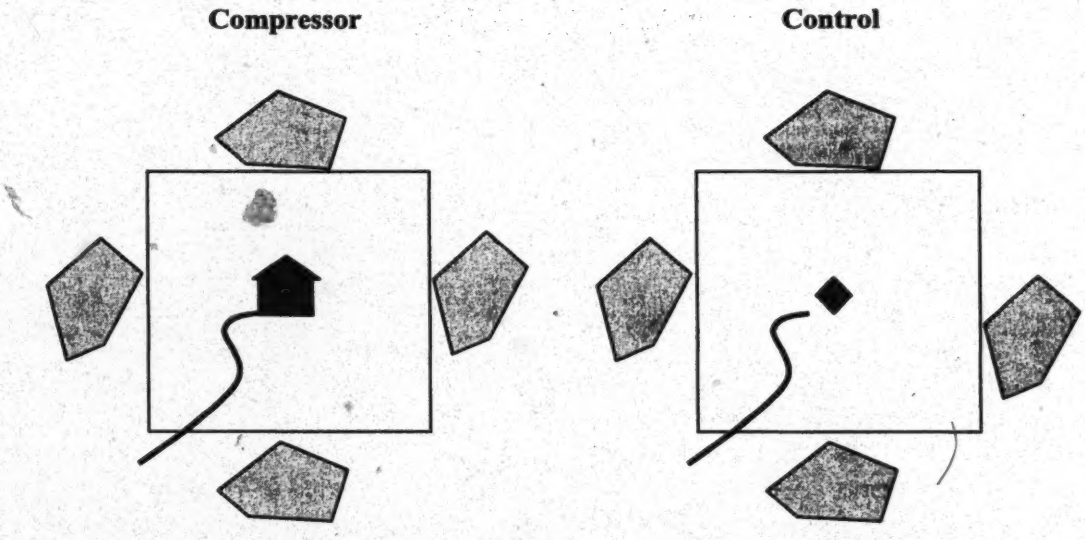

Figure 3.2. Study design for Ovenbird capture in northern Alberta in 2004 and 2005. One Ovenbird was captured on each side of an energy industry-created clearing (territories indicated by grey polygons). Compressor sites had a noise-generating compressor station (house icon) at the centre of the clearing, while control sites had a noiseless wellhead (diamond icon) at the centre.

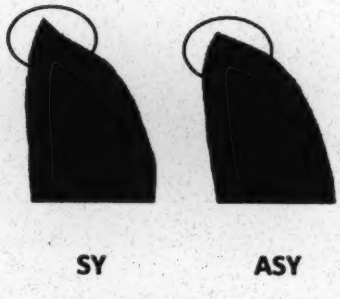

Figure 3.3. Examples of feather tips from a second-year (SY) Ovenbird and an after-second-year (ASY) Ovenbird. Feathers of SY birds have a sharper tip angle as is highlighted.

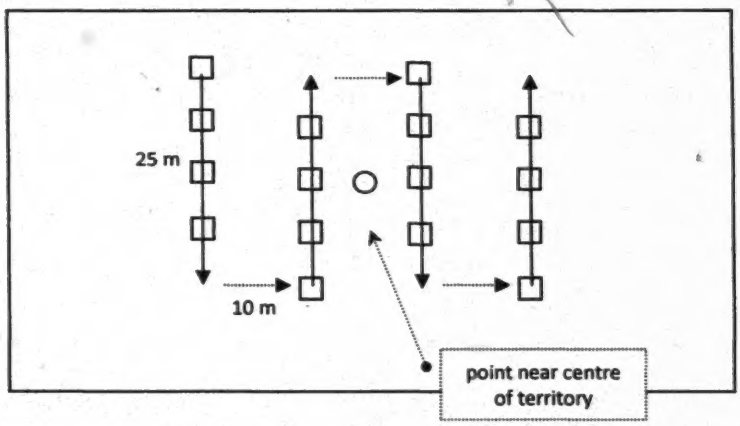

Figure 3.4. Ovenbird territory vegetation assessment protocol. All trees intersecting the 1-m wide transects had their DBH measured, and all DWM intersecting the transects were tallied. In the 0.25-m^2 plots, shrub density, leaf litter depth, and grass, moss, and forb cover were measured. The study was conducted in northern Alberta in 2004 and 2005.

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CHAPTER 4. SONG ALTERATION AS A CONSEQUENCE OF CHRONIC BACKGROUND NOISE

4.1 Introduction

In previous chapters, I discussed the importance of song to birds and possible issues which may arise should an increase in background noise conflict with those songs. However, if birds are able to behaviourally adjust for noise pollution in their environment, negative effects of anthropogenic noise may be mitigated. For example, Naguib (1996) found that Carolina Wrens (*Thryothorus ludovicianus*) gauge distance to a singer differently before and after foliage had developed, implying that birds have the ability to alter their distance-judging criteria based on context. It should, however, be noted that foliage emergence is a predictable pattern which occurs on an annual basis, unlike anthropogenic noise.

Anthropogenic noise has been shown to cause problems for song learning. When exposed to continuous white noise in a lab setting, adult Zebra Finches (*Taeniopygia guttata*) developed severely abnormal song patterns (Zevin *et al.* 2004). As little as one noise-free hour a week was sufficient for birds to receive proper song feedback and adjust their song to maintain normal singing patterns (Zevin *et al.* 2004).

However, birds may also be able to alter the structure of their song in order to minimise interference with background noise. This may be accomplished in two ways: through an increase in the amplitude of the song or through a shift in frequency (pitch) to move the song away from the frequency band occupied by the noise (Katti and Warren 2004; Figure 4.1). The Lombard effect, a reflexive short-term increase in vocal amplitude, is a well-studied response of animals to background noise (Warren *et al.* 2006). In lab settings, it has been demonstrated in Zebra Finches (Cynx *et al.* 1998) and Budgerigars (*Melopsittacus undulate*; Manabe *et al.* 1998). In a field setting, Brumm (2004) found that Nightingales (*Luscinia megarhynchos* Brehm) living near roads had higher amplitude songs under higher noise levels. Furthermore, Brumm (2004) found that the same birds sang at lower amplitudes on weekends, when less traffic noise was present. However, it is incredibly difficult to accurately measure amplitude in the field due to the plethora of factors in the natural environment which may affect it.

The other way in which birds may alter their song to avoid noise interference is by shifting the song's frequency. Slabbekoorn and Peet (2003) demonstrated that the minimum song frequency of Great Tits (*Parus major*) increases with increasing maximum frequency and amplitude of background noise in an urban environment; birds in noisier territories had higher minimum song frequencies. This pattern is much easier to test in the field, as song frequency is not dependent on horizontal or vertical distance to the bird or other such nuisance factors.

If birds in industrial areas are able to behaviourally raise their song frequency in order to transmit above the level of the low-frequency mechanical noise, potential communication problems could be avoided. In this chapter, I test the ability of the Ovenbird, Swainson's Thrush, and Red-eyed Vireo to raise the minimum frequency of their song in areas around compressor stations. In Chapter 3, I found that all three species have reduced densities near compressor stations. Vireos showed the strongest response; they were found to have lower densities at compressors by all four of the conducted analyses. Thrushes had lower densities at compressors by two of the four analyses. Ovenbirds fell in between; they had lower densities at compressors by two of three applicable analyses. Based on this information, I hypothesized that Vireos would be unable to adapt their song to high levels of industrial noise and therefore avoid these areas; Ovenbirds suffer from reduced ability to attract a mate and reduced density in noisy areas and thus probably cannot adjust their song; while Thrushes might have the ability to adjust their song in those areas and as a result are more likely to have similar abundances in noisy and quiet areas.

4.2 Study Area

4.2.1 Location

In 2004, I made song recordings of Ovenbirds that had been captured for pairing success analysis in the NEA. In 2005, I recorded Swainson's Thrushes and Red-eyed Vireos in the NWA.

4.2.2 Site selection

I defined two sets of sites at which the project was carried out – compressor sites and control sites, as described in §2.2; however, we targeted compressor sites for recording. Recordings from control sites and compressor sites were lumped together as the independent variable used for all analyses was maximum frequency of background noise, not treatment as in Chapters 2 and 3.

4.3 Methods

4.3.1 Song recording

Song and background noise recordings were conducted following the protocol of Slabbekoorn and Peet (2003; H. Slabbekoorn, pers. comm.). For song recording, I used a Sennheiser ME67 shotgun microphone, connected to a Sennheiser K6 powering module and a Sony digital audio tape recorder (TCD-D7). All birds recorded were located <250 m from the site centroid. When a bird had been targeted for recording, the observer attempted to quietly get within 20 m of the bird. The microphone was pointed at the bird during recording; if it was at a compressor site the microphone was oriented to be perpendicular to the source of the noise as the microphone is least sensitive to sound emanating from that direction.

Once bird song recording was completed, the shotgun microphone was switched for a Sennheiser ME62 omnidirectional microphone in order to record background noise. For these recordings, the microphone was pointed directly up.

4.3.2 Song analysis

Songs were transferred to computers in the Songbird Neuroethology Lab operated by Dr. Chris Sturdy at the University of Alberta. Songs were analysed using SIGNAL 4.0 (Engineering Design, Berkeley, CA). For each recorded song, I measured minimum frequency and frequency at peak amplitude (Bloomfield *et al.* 2004). This was then related to maximum frequency of background noise, as measured from the omnidirectional recordings. Song parameters were compared in a linear regression. I used Cook's distance to estimate the influence of each individual point in order to

eliminate possible outliers (Fox 1991). For Ovenbirds, the additional independent variable "body" (§3.3.5) was included as a covariate as body size is known to influence song characteristics, including frequency (Ryan and Brenowitz 1985). Those data were not available for Swainson's Thrushes or Red-eyed Vireos.

4.4 Results

I obtained multiple song recordings for Ovenbirds (n_{comp}=25, n_{ctrl}=18), Red-eyed Vireos (n_{comp}=28, n_{ctrl}=13), and Swainson's Thrushes (n_{comp}=8, n_{ctrl}=13). Mean background noise maximum frequency at all recording locations combined was 1.18 kHz for compressor sites, compared to 0.58 kHz for control sites (one-tailed t-test: t=6.48, df=109, P<0.001). Maximum background noise frequency was not a significant predictor of frequency at peak amplitude for any of the three species. Minimum frequency of song for Ovenbirds did not exhibit a significant response in this parameter with respect to maximum background noise frequency (β=0.12, R^2=0.04, P=0.18; Figure 4.2). Adding body condition into the regression as a covariate had minimal effect on the treatment parameter (β=0.14, R^2=0.05, P=0.15).

Swainson's Thrush showed a significant increase in minimum song frequency with an increase in maximum background noise frequency (β=0.16, R^2=0.18, P=0.05). The Thrush data fit the model far better than the data for the other two species. The case with the highest maximum background noise frequency had a Cook's distance value of D=0.61, indicating that it has greater influence on the model than the other points (all having D<0.2). Fox (1991) suggests a cut-off of $D > 4/(n-k-1)$, where k is the number of independent variables; consequently this point was removed from the dataset, resulting in a stronger relationship, fit, and significance (β=.25, R^2=0.21, P=0.04; Figure 4.3).

Minimum song frequency of Red-eyed Vireos did not vary with maximum background noise frequency; however, there was a slight trend towards higher minimum song frequency at sites with *lower* maximum background noise frequencies (β=-0.13, R^2=0.07, P=0.08). Again, one point had greater influence than the others (D=0.34 while all other points had D<0.11) and exceeded Fox's (1991) cut-off. Discarding this point weakened the fit of the model, and although the trend is the same the P-value increased (β=-0.08, R^2=0.04, P=0.23; Figure 4.4).

4.5 Discussion

Results from this analysis were consistent with my hypotheses. It appears that in its natural environment, Swainson's Thrush was able to increase the minimum frequency of its song in the face of background noise. Furthermore, Swainson's Thrush has the lowest-frequency song of the three species, typically ranging from 1 to 5 kHz (Borror and Gunn 1985). Because of this, its song is more likely to overlap low-frequency industrial noise and therefore birds may have been forced to alter it in order to inhabit those areas.

The sample size of Thrushes in this experiment was small (n=21 and n_{comp}=8), in part because of their lower density in the boreal forest relative to Ovenbirds and Red-eyed Vireos. They are also difficult to locate due to the somewhat ethereal nature of their song. Nevertheless, the results are suggestive, but a larger sample size is required to be strongly conclusive. The ability of Thrushes to respond to background noise in this way should also be tested in a lab experiment; to the best of my knowledge, frequency shifts in birdsong as a response to noise have not yet been lab-tested. Before comprehensively testing whether birds have this ability in nature, it may be prudent to see if it is possible within a strictly-controlled lab setting.

The weak inverse relationship between minimum song frequency and maximum background noise frequency observed in Red-eyed Vireos was an unexpected – although not significant – result. A possible explanation is that Vireos have a highly variable song, ranging in frequency from 1.5 to 8.5 kHz (Borror and Gunn 1985). As well, Vireos sing at a rate unrivalled by most other species. Consequently, if some notes at the lower end of the range drop out due to background noise, it may be less detrimental to a Vireo than to individuals of other species.

Ovenbirds had a weak relationship between minimum song frequency and maximum background noise frequency. Nevertheless, I feel that they are less likely to adapt their song to the situation than Swainson's Thrush. Ovenbirds have a high-amplitude song relative to other species, which may help offset any frequency overlap that exists. Their song, with a frequency range of 2.2 to 7 kHz (Borror and Gunn 1985), may overlap with the extreme upper end of the industrial noise frequency range. While this overlap could be enough to cause problems with communication (Slabbekoorn and Peet 2003, Slabbekoorn 2004), it is likely slight enough that any vocal response system of

Ovenbirds is not triggered. Within a population of Ovenbirds, many song phrase structures are present; however, each male typically has his own phrase structure and very rarely sings another (Lein 1981). This suggests that Ovenbirds may not have the capability to adjust their songs in response to a changing environment, unlike other species in which males have a large repertoire of phrases (Lein 1981). As well, Ovenbirds have high-amplitude songs relative to other wood warblers and therefore may not need to change the frequency of their song in order to transmit somewhat effectively.

While this was a simple analysis, I employed robust methodologies. Ideally, I would have known the body size and condition of all species used, and made recordings of the same individual over multiple days, but these were impractical to conduct due to logistical concerns and time constraints. I feel strongly that a more comprehensive version of this study would prove fruitful; including more individuals in the study, having more information on those individuals, and possibly analysing other species could provide insight into the severity of noise overlap with birdsong and possible coping strategies employed by individuals.

If unable to behaviourally modify their song, birds may have other mechanisms for dealing with high ambient noise levels. Animals are able to focus on an auditory signal despite a low signal-to-noise ratio; this has been termed the "cocktail party effect" (Slabbekoorn 2004). Call rates may also increase in the presence of noise, allowing females to hone in on a male's location through his repeated calls. Anthropogenic noise causes some "acoustically-active" amphibian species to lower their call rate, which in turn stimulates less active species to increase theirs (Sun and Narins 2005).

4.6 Conclusions

I have shown support for the idea that Swainson's Thrush can adjust the form of its song to deal with anthropogenic background noise. Birds immigrating to an area modify their songs and calls to match those of residents (Rabin and Greene 2002); this may act as a mechanism for transmission of song alterations. Over a short period of time, a few birds who have managed to adapt their song could drive a shift in song frequency throughout a population (Rabin and Greene 2002). Ultimately, this provides the potential for evolutionary divergence between conspecifics living in anthropogenically noisy and quiet environments (Slabbekoorn and Smith 2002a, Warren *et al.* 2006). This same endpoint could also be reached through differential selection of males by females in anthropogenically-noisy habitats due to the series of communication issues discussed earlier.

In Cameroonian rainforest, Little Greenbul (*Andropadus virens*) song varied concomitantly with natural ambient noise (Slabbekoorn and Smith 2002b). This pattern has also been extended to anthropogenic noise in the Orange-tufted Sunbird (*Nectarinia osea*), an old-world territorial passerine. The Sunbird has numerous populations characterized by discrete song dialects throughout its range. Leader *et al.* (2005) found two dialect-populations, with a sharp boundary between them, in a 1.5-km^2 urban habitat in Israel. The song of the Sunbird ends with a long trill; in these two populations the trills have means of 5 and 8 kHz. In general, the "high dialect" birds were found near a four-lane expressway while the "low dialect" birds were located deeper into the subdivision. However, the authors felt that they could not clearly state that the noise from the expressway was the cause of this pattern (Leader *et al.* 2005).

The timescales required for genetic adaptation are usually quite long. Consequently, the rapid rise of anthropogenic noise on the landscape, especially in boreal Alberta, is unlikely to lead to selection for specific song characteristics (Rabin and Greene 2002). However, the ability of some species to quickly learn to modify their songs may provide an alternative coping mechanism for facilitation of communication in noisy environments.

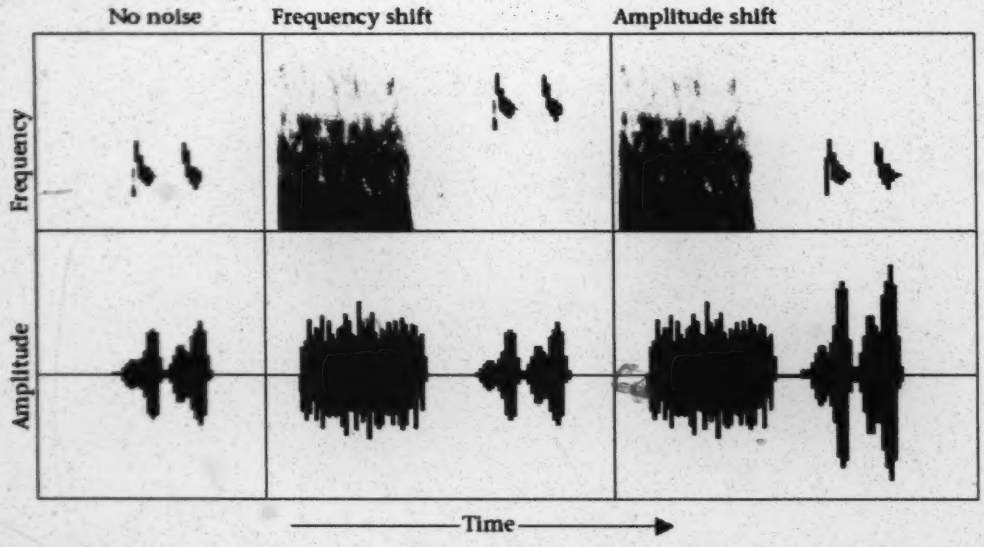

Figure 4.1. Birds may adjust their song in the presence of background noise to reduce interference with the noise. There are two ways this may occur: by shifting the song's frequency to a region on the spectrum with less overlap, or by increasing the song's amplitude. When the latter occurs as a short-term reflex response, it is called the Lombard effect and has been demonstrated by many species (Reprinted with permission from Katti and Warren 2004).

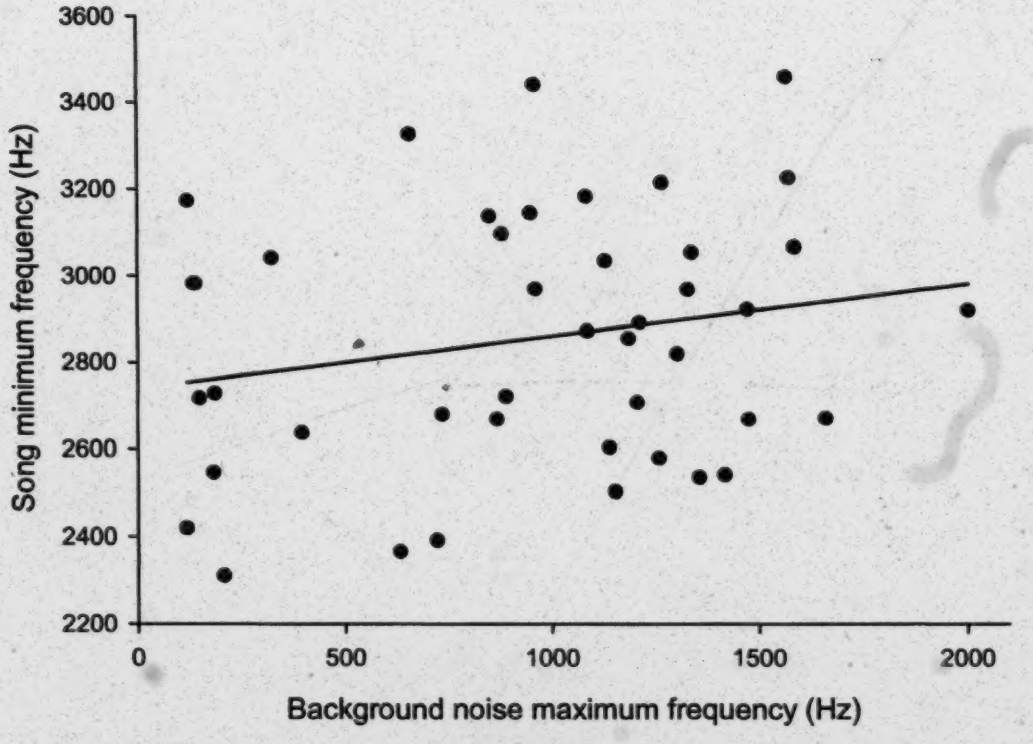

Figure 4.2. Minimum frequency of Ovenbird song increases slightly with increasing maximum frequency of chronic industrial background noise (β=0.12, R^2=0.04, P=0.18). Recordings of edge-dwelling male birds were made in northeastern Alberta during the 2004 breeding season.

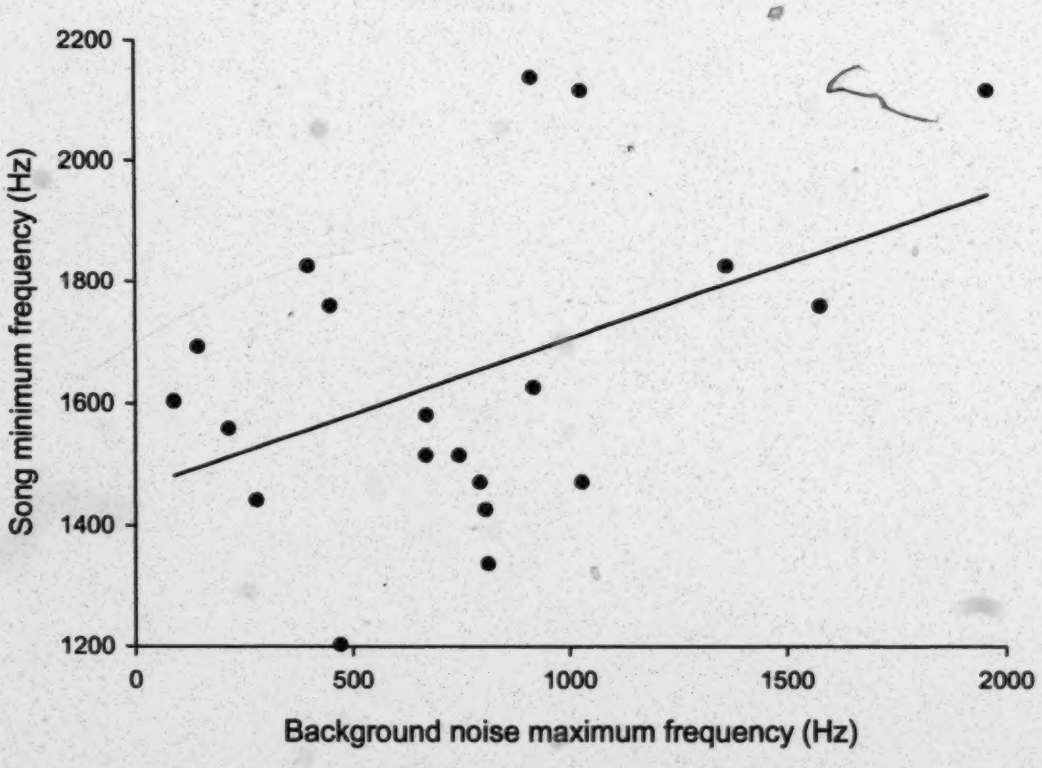

Figure 4.3. Minimum frequency of Swainson's Thrush song increases with increasing maximum frequency of chronic industrial background noise (β=.25, R^2=0.21, P=0.04). Recordings of edge-dwelling male birds were made in northeastern Alberta during the 2005 breeding season.

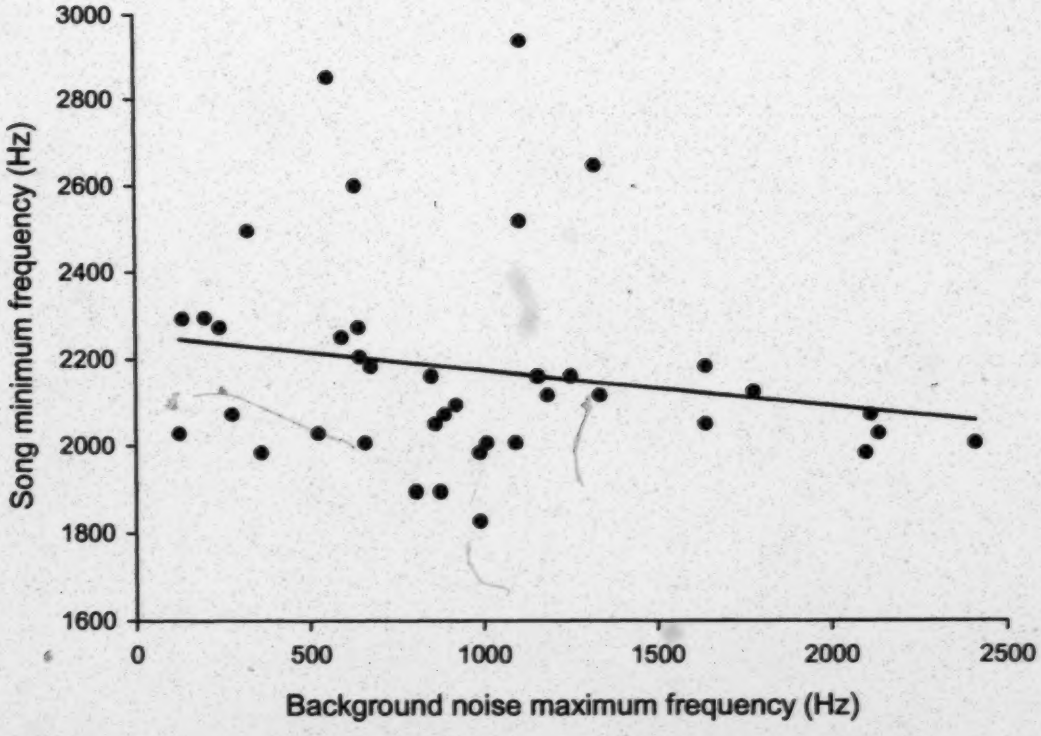

Figure 4.4. Minimum frequency of Red-eyed Vireo song decreases slightly with increasing maximum frequency of chronic industrial background noise (β=-0.08, R^2=0.04, P=0.23). Recordings of edge-dwelling male birds were made in northeastern Alberta during the 2005 breeding season.

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CHAPTER 5. SYNTHESIS AND MANAGEMENT IMPLICATIONS

5.1 Synopsis of Findings

The purpose of this study was two-fold: 1) it assessed the effects of increasing noise in the boreal forest due to expanding energy industry infrastructure, and 2) it enabled a broader examination of noise impacts on birds without any confounding covariates present in other "road noise" studies. Specifically, I found that passerines as a whole, as well as some specific species, appear to avoid noisy areas. The Ovenbird had reduced pairing success in noisy areas. There were also a significantly greater proportion of first-year breeders in those areas. However, two species (Tennessee Warbler and Yellow-rumped Warbler) showed some evidence of attraction to compressor stations. Finally, the Swainson's Thrush appeared to be able to shift the frequency of its song to be higher than that of the background noise, although other species may not have this ability.

5.2 Limitations and Future Research

Despite the general trends and implications of my work, there are some limitations which should be discussed. Chief among these is the issue of detectability. While I attempted to account for any potential differences in detection probability between point count sites by using a variety of methods, what is truly needed is a comprehensive examination of which of these methods provides the best density estimates. This can only be done by comparing all of to a reference population in which every bird is known. This is, of course, a formidable task. Performing the experiment in a closed environment would not adequately replicate a field situation. Performing it in the field with reference values provided by spot-mapping is a better alternative; however, spot-mapping without banding individuals also has biases such as inaccurate clustering of points to delineate a territory. Ultimately, a spot-mapping approach with a banded population of birds would be ideal.

While I did measure noise amplitude at each point count and bird capture location, I decided against using these values in the analysis. Statistically, it was difficult to integrate varying levels of noise at compressor sites with presumed "lack" of noise at control sites; no place is *completely* silent, only lacking in anthropogenic noise. An

analysis patterned after a medical study could be attempted (*e.g.* in smoking studies, non-smokers have zero nicotine intake while smokers have varying levels), but this type of methodology can be extremely complex (Robertson *et al.* 1994, Greenland and Poole 1995, Breslow 1996). Ideally, a similar study in the future would be better able to incorporate actual noise amplitude measurements through rigorous measurement protocols and robust statistical analyses.

While I found that many species exhibited reduced densities in noisy areas, and that at least one species had reduced pairing success near compressor stations, birds may be avoiding these areas for other, unexplored reasons. Future research in this area should examine the effects of chronic noise on stress levels in birds, which has been postulated as a mechanism for reduced bird density near roads (Reijnen *et al.* 1995). Campo *et al.* (2005) found that pre-recorded mechanical noises such as fans and vehicles increased stress levels in laying hens, and that the level of that stress was directly related to noise amplitude. Tempel and Gutiérrez (2003) measured fecal corticosterone levels in the California Spotted Owl (*Strix occidentalis occidentalis*) exposed to one-hour bouts of low-intensity chainsaw noise from logging operations. They found that stress levels did not increase; however, they had a low sample size (n=9), expressed doubts about the accuracy and reliability of fecal corticosterone testing (Tempel and Gutiérrez 2004), and noted that one hour of noise may be too short a time period to have an observable effect on stress levels. The analysis of blood corticosterone levels as a proxy for bird stress is a common but expensive procedure, and there are some concerns with data quality (Wingfield 1994, Romero and Romero 2002). This was originally intended to be part of my study, but logistical constraints, such as the availability of low-temperature freezers in a remote field setting, prevented it.

Another potentially fruitful area for future research is the expansion of the song adaptation question. As mentioned in §4.5, testing the ability of various songbird species to shift the frequencies of their songs when exposed to chronic noise in a lab setting would give us a better idea of how we could expect birds to react to those stimuli in their natural environment. Again, repeating this experiment with an increased sample size and other candidate species would also prove informative.

5.3 Current Noise Guidelines and Recommendations

The first Alberta Energy and Utilities Board (EUB) noise control directive was published in 1973 and stated that energy industry facilities could not exceed certain noise levels at nearby residences: 65 dB(A) during the day or 55 dB(A) at night (DeGagne 1999). In 1988, the policy was updated with various protocols for more accurate noise measurement based on acoustic principles. The most recent version of the guidelines, *Noise Control Directive ID 99-08*, and its associated *User Guide 38*, expand voluntary noise guidelines to wilderness areas which are uninhabited by humans (AEUB 1999a; 1999b). They state:

> "[even] for remote facilities where there are no impacted dwellings, uncontrolled sound generation is not allowed, particularly since retrofit may be required if a residence is built and the facility is no longer remote. New facilities planned for remote areas should be designed to meet a target sound level of 40 dB(A) Leq [average noise level over a given period of time] at a distance of 1.5 km, although this is not a mandatory requirement. (Using the rule of 6 dB(A) loss per doubling of distance from the source, the facility would generate a sound level of approximately 70 dB(A) at 50 m.) As a target, this does not establish compliance should infringement occur." (AEUB 1999b)

While noise generation in remote areas is recognized as a problem in this Directive, it still emphasizes an anthropocentric view that noise control is only a concern since residences may be constructed near the facility at a later date, and the facility would then have to be retrofitted at increased cost. I argue that noise should be considered as an industrial impact on wildlife as well as on humans.

Some of the compressor stations used in this study had noise levels slightly greater at 50 m from the noise source than those specified in *ID 99-08*, but all were <75 dB(A) at that distance. My findings suggest that current EUB noise emission targets are likely set too high to avoid negative impacts to birds. Technology to reduce noise emissions from compressor stations and other facilities currently exists. Although it would increase the cost of constructing these facilities, I propose that the current guidelines be made more stringent by lowering the maximum permissible noise levels and designating them as mandatory rather than voluntary.

As energy development permeates boreal Alberta, noise will be increasingly difficult to avoid. As discussed in Chapter 2, noise-affected area estimates vary based on the criteria used to define "impact" (*e.g.* decreased fitness, avoidance), but it appears that at the very least, birds holding the closest territories to the noise source will be impacted in some respect. For common, highly-territorial species such as the Ovenbird, a decrease in the availability of quiet habitat could directly lead to a population decrease as its density in boreal Alberta among the highest in its range (E. Bayne, pers. comm.). It could also result in behavioural effects such as decreased numbers of floaters, or non-territorial birds, in noisy areas (Bayne and Hobson 2001). Consequently, noise readings and noise-impacted area estimates should be considered in future environmental impact assessments conducted for noise-generating facilities.

With respect to other noise sources, I recommend that recreational access to seismic lines be diminished. While there are numerous other reasons to limit access (*e.g.* increased vegetative regrowth on seismic lines, reduced wildfire ignition risk), noise from all-terrain vehicles is penetrating the boreal forest with increasing human presence. While this cannot be considered chronic noise, it is similar to vehicle traffic and in some areas, at certain times of year, can be quite intense. In the interest of minimising forest fragmentation as well as noise-affected area, roads, seismic lines, and rights-of-way should be coordinated and shared between energy and forestry operations.

To date, our consideration of industrial impacts on the boreal forest have focused nearly exclusively on physical effects. This research has shown that other, less-obvious factors can also influence wildlife in a variety of ways, and should be taken into account in future impact evaluations. Finally, I suggest that in light of new evidence indicating that animals respond to chronic industrial noise, the term "cumulative effects" should not refer to solely physical factors, but should evolve into a comprehensive term encompassing all impacts on the boreal forest and the relationships between them.

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